UNIVERSAL
LIBRARY

109 144

UNIVERSAL
LIBRARY

THE PHOSPHATES OF AMERICA.

WHERE AND HOW THEY OCCUR; HOW THEY ARE MINED; AND WHAT THEY COST.

WITH

PRACTICAL TREATISES

ON THE

MANUFACTURE OF SULPHURIC ACID, ACID PHOSPHATE, PHOSPHORIC ACID, AND CONCENTRATED SUPERPHOSPHATES, AND SELECTED METHODS OF CHEMICAL ANALYSIS.

BY

FRANCIS WYATT, PH. D.

FIFTH REVISED EDITION.

NEW YORK AND LONDON.

THE SCIENTIFIC PUBLISHING CO.

1894.

COPYRIGHTED, 1891, BY
THE SCIENTIFIC PUBLISHING COMPANY.

THIS BOOK

IS

DEDICATED TO MY FRIEND

RICHARD P. ROTHWELL

Editor of The Engineering and Mining Journal,

AS AN HUMBLE TRIBUTE OF MY ESTEEM

AND HIGH CONSIDERATION.

PREFACE.

THE self-explanatory title of this book enables me to dispense with a lengthy introduction, nor, if I were to write one, could I add anything to what I have endeavored to say in its pages.

It embodies many facts, figures and suggestions resulting from long observation and an extremely varied practical experience; and while these are designed for the exclusive use of specialists, I trust that, taken altogether, it will prove highly profitable reading to all those numerous classes directly or indirectly interested in the production, manufacture, sale and consumption of commercial fertilizers.

I have endeavored to couch it in common, every-day language, and have avoided as far as possible all unnecessary chemical formulæ and technical terms. In a word, my aim and ambition have been to make it intelligible and useful to the ordinary careful reader, and if I have partially succeeded in this, I shall be more than repaid for the labor it has cost me.

THE AUTHOR.

LABORATORY OF INDUSTRIAL CHEMISTRY,
12 PARK PLACE, NEW YORK.
November, 1891.

TABLE OF CONTENTS.

INTRODUCTION TO FIFTH EDITION iii

CHAPTER I.—INTRODUCTORY—GENERALITIES 9

CHAPTER II.—PHOSPHATES AND THEIR ASSIMILABILITY 17

CHAPTER III.—THE PHOSPHATES OF NORTH AMERICA 27

CHAPTER IV.—THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA.... 45

CHAPTER V.—THE PHOSPHATE DEPOSITS OF FLORIDA 63

CHAPTER VI.—SULPHURIC ACID MANUFACTURE..... 84

CHAPTER VII.—THE MANUFACTURE OF SUPERPHOSPHATE, PHOSPHORIC ACID, AND "HIGH-GRADE SUPERS." 106

CHAPTER VIII.—SELECTED METHODS OF PHOSPHATE ANALYSIS AND GENERALLY USEFUL LABORATORY DETAILS 138

CHAPTER IX.—LIST OF FLORIDA PHOSPHATE MINING COMPANIES .. 179

INDEX..... 183

THE PHOSPHATES OF AMERICA.

INTRODUCTION TO THE FIFTH EDITION.

ALTHOUGH I have endeavored for a great many years to more or less identify myself with the industry of phosphate mining in the United States, I should probably never have undertaken to publish the collective results of my observations of our phosphate beds, had I not been compelled to camp out in the woods of Florida during the winter months of 1889–1890. For very nearly the whole of that time, I spent my days in exploring and following up the immense belt of phosphate which has since proved such a disturbing factor in the world's fertilizer markets, and devoted my evenings to compiling my notes and writing my reports. As these reports were numerous and soon grew in volume, it gradually dawned upon me that I might use them as a foundation for a popular descriptive chapter on the mode of occurrence of Florida phosphates, and that I might supplement this chapter by two others, also based upon my own reports, on the deposits of South Carolina and Canada.

I therefore prepared and laid out the general plan for the "Phosphates of America," and on my return to New York gathered together the data I had collected, and appropriated my spare hours to the task of so arranging it as to make it intelligible to the general as well as to the strictly technical reader.

The rapid resumption of routine professional duties, however, and the accumulation of other work, soon interfered with my project and diverted my thoughts into incompatible channels. The

manuscript was consequently passed over to the publishers rather too hurriedly and, although I am gratified at the very ample manner in which all my material conclusions and predictions have been confirmed, certain little errors of omission and commission crept into my work and passed with it through its first four editions, for which I unhesitatingly throw the responsibility on its lucubratory origin. In the present edition, which I have reviewed with great minuteness and corrected in detail, I have had the satisfaction of introducing some necessary modifications in that section of the chapter on chemical analysis which deals with the determination of iron and alumina. I have also partly rewritten my chapter on Florida, and, in the light of the past three years' continuous and wide practical experience have generally brought the entire subject of the book "up to date"! This being the case, it is not necessary for me to attempt any prefatory amplification of what I have said in the body of the volume, but I may nevertheless beg permission to dwell upon a few salient facts which have been already too long ignored and which, in my opinion, should now become generally known and understood.

As the result of much patient inquiry and study of the subject I have been able to show that, if all the farmers of the world were to replace—as they should do—that portion of the phosphate of lime which is taken from their soils by the food crops, exported, and irretrievably lost, it would entail a consumption of some 12,000,000 tons of mineral phosphates every year. Of this quantity, calculated to an average quality of 60 per cent. tribasic phosphate of lime, about 4,000,000 tons should be used up in the United States alone, the remainder being distributed among the principal European countries. Instead of attaining these enormous figures, however, the total phosphates of mineral origin of all grades and from all sources actually used for fertilizing purposes does not exceed 2,000,000 tons per year.

The difficulty of accounting in any logical way for this startling discrepancy would seem to be insuperable, and I can offer no better explanation of it than the fact that the great majority of farmers are far from wealthy, and are neither very advanced in knowledge nor sufficiently imbued with the commercial instinct to understand the necessities of their position or the requirements of their soils. In nine cases out of every ten, when they purchase fertilizers at all, they purchase those with high-sounding names and of needlessly complex composition, and, speaking in a general way, pay

for them "through the nose." Their true position may therefore be summed up somewhat as follows:

First.—They are ignorant of the proper kind of fertilizers required by their soils and for the crops they prefer to produce.

Second.—They are entirely dependent upon these crops; their purchasing power being regulated by the returns from their lands.

Third.—They lack capital and have but a restricted credit, owing to the existence of mortgages.

Fourth.—They purchase their fertilizers under the guidance of some local "middleman" or manufacturer's agent, whose chief object is to sell that class of fertilizer which leaves the greatest margin of profit to the maker.

Fifth.—Their crops are frequently destroyed by such natural causes as floods, drought, frost, fire, insects; they are consequently unable to pay when their notes fall due for the fertilizer purchased, and are compelled to wait for another and more favorable season before they can get out of debt and buy any more.

If I have not exaggerated these circumstances, they explain sufficiently for my purpose the reason why more than two-thirds of the world's farmers are not to be counted as yearly buyers of phosphatic fertilizers, and why their consumption of them will always be subject to the fluctuations of their fortunes. In other words, I should say that the increase in their total demands will always be a gradual one, and while it will no doubt steadily develop with their better knowledge of agricultural science, it will always go by leaps and bounds in years of prosperity, and be just as invariably subject to a retrograde movement, when the harvests decrease.

At the present time the quota to the world's requirements supplied from the phosphate deposits of the United States is about 700,000 tons per year of a quality averaging 65 per cent. This represents more than one-third of the total quantity of mineral phosphate actually consumed, and, without counting any bubble or speculative enterprises, the cash capital invested in the mines and mining plant that produce it amounts to something over $20,000,000.

Regardless of their eventual destination or place of consumption the actual cost of mining, dressing, loading, and transporting the various grades of American phosphate to those points most accessible either for ocean or inland transportation, based on the approximate output, is about as follows:

	Per ton.
200,000 tons Florida rock, averaging 78%, at Fernandina ..	$5.50
150,000 " " "pebble," " 65%, at Tampa	3.50
400,000 " South Carolina rock, 58%, at Charleston ...	3.50
750,000 tons total output, average 65%, cost	$4.00
The depreciation of plant, office expenses, management, etc., are estimated to be.....	20
Making a grand total of.....	$4.20

Under the existing circumstances engendered by the short-sighted policy of our miners, the average selling price of this phosphate cannot be placed at a higher figure than 10 cents per unit free on board cars or vessels at any points for which the foregoing estimate of cost has been compiled. I consequently formulate the following estimate of the average profit of our phosphate mining as it is now carried on:

VALUE OF THE PHOSPHATE AT SHIPPING PORT.	
750,000 tons of phosphate, averaging 65%, at 10 cents per unit	$4,875,000
COST OF THE PHOSPHATE AT SHIPPING PORT.	
750,000 tons of phosphate, averaging 65%, at $4.20....	$3,150,000
Total balance available for interest on capital of $20,000,000.....	$1,725,000

Lest these figures of cost and value should be deemed imaginary I hasten to say that they are compiled from the books of certain large mining companies with which I am professionally connected, and I think they prove very conclusively that so long as our mines can collectively supply 750,000 tons of phosphate per annum without material increase in the present cost of production, they will return an average profit representing seven and one-half per cent. interest per annum on the capital invested. This profit will of course increase in direct proportion with the increase in production, but how such increase is to be sold without still further lowering prices, and whether we could look to Europe as a customer for it, in face of the keen competition which we are now compelled to sustain with the mines of France, Belgium, and the West Indies, and which will soon be added to by those of Tunis and Algeria, it is extremely difficult to surmise. In any event, I take the position—and defy controversy—that the marvellous profits so long supposed to be derived from the phosphate mining industry are now shown to be altogether fallacious, and that they are literally less than those

generally attributed to an ordinary manufacturing business. I therefore maintain that they are entirely incompatible with enormous risks, and especially with the risks involved in the prevailing methods of dealing with European buyers.

It is perhaps hardly necessary to emphasize the fact that the trade in fertilizing material is subject to the same fluctuations as those which characterize all other natural products. Until a few years ago the demand for phosphates of good quality was in excess of the available supply, and hence, as a perfectly natural consequence, the miners of phosphate were able to realize large profits from their operations. When this became popularly known it is only natural that there should have been attracted to the industry more and more of that surplus capital which is always seeking for remunerative investment, and that the impetus thus acquired should have resulted in an ever-increasing production.

Before the discovery of the immense deposits of Florida, for example, the average net profit per ton from a good, accessible, and productive high-grade phosphate mine was somewhere in the neighborhood of $7. With this very large margin before him, the miner could well afford to take the risk of consigning his product to foreign buyers, and he had an additional security, derived from the comparative scarcity of the product, which insured his being treated by them with ordinary fairness. The present large increase in production, and the consequent keen competition, have, however, now combined to deprive him of both these points of vantage, and he is no longer in a position to dictate his conditions. He is, on the contrary, entirely in the hands of his buyers, who squabble over differences in analyses, which they were formerly wont to regard as entirely insignificant, and summarily reject whole cargoes for the most trifling causes, even after the phosphate has been taken out of the vessel and delivered into their own factory. In the majority of these rejection cases the difficulty is settled by an enormous sacrifice in value, but there are not a few of them, which have come within my own knowledge, where heavy damages have been exacted for comparatively small deficiencies in the stipulated guarantees.

Without dwelling at any greater length upon these facts, it seems to me that they will, if considered in an impartial spirit, inevitably point to the necessity for a radical change in the attitude of the sellers. In the present state of the phosphate industry the loss involved by the rejection of a single cargo is quite sufficient to

counterbalance all the profits derived from an entire year's work in an average mine, and the only practical and rational safeguard for our phosphate miners is the absolute and unanimous adoption of some such conditions as the following for all future sales to foreign buyers:

First.—The acceptance of American weights and American analyses.

Second.—The acceptance or rejection of the phosphate before vessels are loaded, upon the results of such methods of sampling and analysis as may be mutually arranged.

All losses of a strictly commercial nature would thus come to an end, the risks attending the fluctuations of freight rates would be, as they should be, forever obviated to the miner, and the temptations to reject cargoes now offered to buyers by the variations in market prices pending the execution of contracts would be withdrawn.

As I have already said, however, it is questionable whether we can look for any more immediate profitable development of our foreign trade, and in any event it behooves us to devote greater attention to popularizing the use of phosphates in our own vast territory, and to making our natural resources more available for our own needs.

As our farmers become enlightened they will eagerly seize all means of wealth that can be cheaply brought to their doors, and will only be too ready to apply to their impoverished fields the sustenance that phosphate will impart.

No more important duty rests upon agricultural chemists than that of disseminating this practical scientific knowledge for the benefit of exhausted lands. This mission will not merely prove commercially profitable to us as the feeders of the world from the standpoint of manufacture and trade, but will at the same time fully satisfy all the demands of philanthropy, for as Dean Swift has said: "Whoever can make two ears of corn, or two blades of grass to grow upon one spot of ground where only one grew before, will deserve better of mankind and do more essential service to his country than the whole race of politicians put together."

THE AUTHOR.

THE LABORATORY OF INDUSTRIAL CHEMISTRY,
12 PARK PLACE, NEW YORK.

THE PHOSPHATES OF AMERICA.

CHAPTER I.

INTRODUCTORY—GENERALITIES.

THE theory of scientific agriculture is based upon a complete knowledge of the nature of soils, plants, animals and manures, and it is evident that until these elements are thoroughly understood no attempts at improvement or plans for increased production can possibly be successful. Is it not curiously illustrative of the general ignorance that very few people know anything of the earth they tread or the soil they cultivate, in what way it was formed, or of what it is composed? How, then, can they imagine the mighty inundations and the terrible upheavals? How conceive anything of that gigantic disemboweling of the earth-monster, and of the awful torrents of burning lavas which it has vomited forth? Can they realize that our tallest mountains, even those which from their height are covered with perpetual snow, were once submerged in rolling seas? or that the rocks and cliffs we meet with in our plains are nothing more than agglomerated masses of organisms that swarmed the waters? This is a seductive topic; one that might readily carry us far beyond the scope of this small work; and one that, feeling as we do how utterly impotent we should prove in any attempt to do it justice, we would rather not touch upon at all.

Remembering, however, that we are not writing solely for the

scientific or technical, and that we design to interest the general reader, we are bold enough to attempt a brief summary of acquired facts in order to make subsequent arguments more forcible and clear.

We believe it to be generally admitted by our geological teachers that when our globe was launched into space it was a liquid somewhat similar to molten glass, and therefore presented a vastly different appearance to that with which we are acquainted. When this mass began to cool, it probably resembled an immense glass ball, the solidified sides of which were uplifted by the bubbling of the intensely hot liquid mass within. These solid projections formed our mountains, and, passing from the transparent to the opaque, they gradually assumed the crystalline form. What is known as the earth's crust must have resulted from an extraordinarily forcible action consequent upon the fall of temperature. Certain vapors were condensed into acid bodies, and these acids, attacking the alkaline crust, combined with its most powerful bases to form various salts. Some of these salts—such as sulphate of lime or gypsum—were deposited, while others, principally the chlorides, remained in solution and formed the seas. The neutralization of the stronger and more corrosive acids permitted the weaker carbonic acid to develop its activity, and it is this acid which has continued to play the most important part in nature in our own times. Held in solution by the running waters, it attacked and dissolved the various bases which existed in such large quantities in the mountains, and deposited them in the form of carbonates in the valleys. The process of saturation, or neutralization, being entirely accomplished, chemical equilibrium may be said to have become established; the period of great geological catastrophes, therefore, came to an end, and the temperature of the earth gradually sank below the boiling-point. A few volcanic disturbances continued, it is true, to occasionally convulse it; there was the upheaval, splitting asunder and complete overthrow of mountains, the drying up and the division of seas, and the formation of lakes of both fresh and salt water, but they became more and more rare as the temperature continued to cool.

The rocks with which we are all acquainted have grown out of these continuous and still-continuing changes, and it is their decomposition, under the combined influence of the atmosphere and water, during a long period, that has ultimately produced fertile soils containing silicates of aluminum,

potassium, sodium, magnesium, iron; phosphates, sulphates and chlorides.

The soil at first resulting from this gradual decomposition formed very thin layers, in which only the lower orders of plants found sufficient food to fructify, deriving from the air and the rain their carbon, hydrogen, oxygen and nitrogen. In the natural process of death and decay, these fresh elements of fertility, in various states of combination, were transferred by the plants to the soil, which was thus enabled to afford nourishment to a higher vegetation.

It is the general custom to class arable lands according to the nature of their predominating constituents, and thus we allude to soils as sandy, clayey and limey.

Sandy soils are distinguished by their extreme porosity, and are frequently in such a fine state of division that in the dry season the least wind will displace and scatter them in all directions. In such cases they are naturally sterile; but when they are sufficiently moist, they facilitate and encourage the growth of an immense variety of plants of the lower order, which, by their eventual decomposition or putrefaction, form considerable deposits of that valuable substance called humus.

Such soils are more propitious than any others for the development of plants with very delicate or fine roots, such as barley, rye, oats, lucern, lupins, lentils and potatoes; but they require constant attention, and a large and regular quantity of manure, because their porosity permits them to absorb such an abundance of oxygen that all their organic matter is rapidly burnt up.

Clayey soils are heavy and compact, and when they contain more than fifty per cent. of pure clay are onerous to work, and unprofitable to cultivate. It has, however, fortunately been discovered that the addition to them of so small a quantity as two per cent. of burnt lime suffices to so entirely change their nature and consistency, by transforming the silicate of alumina into a porous silicate and aluminate of lime, that it is now an easy matter in districts where lime is cheap and plentiful to overcome this difficulty. In hot countries or in windy regions or in districts where the subsoil is of a very permeable character, good clay lands offer great advantages, and although they periodically require the application of large quantities of reconstituents, they possess the faculty of retaining all the precious elements supplied to them, and of storing them up for the use of successive crops. When they contain a proportion of about ten per cent. of carbonate of lime, or chalk,

they are the best of all soils for the extensive growth of such important plants as wheat, corn, clover, hemp, peas and beans, and of such trees as the chestnut and the oak.

Limey, or purely calcareous, are even lighter than sandy soils, and when, as is sometimes the case, they are very white and dry they are absolutely barren.

Such as these are, however, rarely encountered, for we generally find them mixed with a sufficiency of clay to give them some degree of consistency and render them available for ordinary purposes. Few soils are entirely devoid of lime, owing to the fact that all rocks contain it in greater or lesser proportion, and because it is transported in immense quantities by waters, in the form of bicarbonate, and deposited. If it were otherwise, or if, in the absence of lime, other alkaline substances were not forthcoming, the acid principles secreted by all plants could not be saturated, and the inevitable result would be decomposition and death. In its pure form, however, lime is such an extremely strong base that it is incompatible with life, and hence it never exists in the soil unless it be combined either with carbonic or silicic or sometimes with sulphuric and nitric acids.

It will be thus seen that the study of geology, even if only elementary, enables the agriculturist to more accurately gauge the natural resources of his land, and will teach him how to adapt his ideas upon drainage, irrigation and ploughing to the surrounding circumstances of soil and climate.

It will also prepare his mind for the teachings of chemistry; that science which has done more than any other to improve the general condition of mankind, and which will enable him to obtain the maximum returns from the soil and from plants.

If production is to be cheap it must be rapid and plenteous, yet, as we all know, the progress of unaided nature is slow and methodical, and so chemistry, by investigating the laws which govern the development of all living things and by carefully observing the facts acquired by the practical experience of centuries, has found the means by which the farmer may assist and hasten the natural processes. The work is, of course, still far from complete, but we are at least familiar with the elements essential to plant-growth. We know how these elements are distributed, what portion of them is or should be contained in our soils, and what soils are most propitious for different kinds of plants.

Sixty years ago the science of agriculture was in its infancy.

Our grandfathers could not understand why lands once so fertile and productive should show signs of approaching exhaustion. The light only came to us after we had studied how out-door plants live, whence they obtain their food, of what elements that food is composed and how it is conveyed and absorbed into their organisms. In point of fact, we have discovered that the manner of life in plants is very similar to the manner of life in animals and man. They require certain foods in stated proportions which pass through the process of digestion, they must breathe a certain atmosphere, and they are subject to the influences of heat and cold, light and darkness.

The tissues of their bodies, like ours, are composed of carbon, hydrogen, oxygen, nitrogen and certain mineral acids and bases, such as phosphoric and sulphuric acids, lime potash, magnesia and iron. Since, therefore, it is admittedly necessary for man to constantly absorb a sufficiency of these elements in the form of food, it follows that similar food is required by plants for similar purposes.

Having determined the elementary composition of plants, investigators directed their attention to the analysis of soils, in order to establish comparisons between virgin or uncultivated lands and old varieties which had long been tributaries to every kind of culture.

It was found that in the former there is an abundance of most of the dominating mineral ingredients discovered in plant organisms, whereas in the latter they either exist only in minute proportions or are lacking altogether.

This marked a most important stage in our progress. Argument is no longer necessary to prove that if agriculture is to continue to be the basis of national wealth and prosperity, means must be found of restoring to our soils the chief elements yearly taken away from them by the crops. These chief elements have been shown to be nitrogen, phosphoric acid, and potash, and that they play the most important parts in the functions of vegetation, and are the most liable to exhaustion, is proved by the following figures, borrowed from an address delivered by Prof. H. W. Wiley at the Buffalo meeting of the American Association for the Advancement of Science.

According to this careful and painstaking chemist, the estimated mean annual values of some of the agricultural products of the United States closely approach the following figures:

Wheat	450,000,000 bushels, valued at		$440,000,000
Maize	1,900,000,000	"	627,000,000
Oats	600,000,000	"	168,000,000
Barley	60,000,000	"	33,000,000
Rye	25,000,000	"	14,000,000
Buckwheat	13,000,000	"	7,280,000
Potatoes	200,000,000	"	100,000,000
Butter, milk and cheese		"	380,000,000
Fruits		"	100,000,000
Rice	98,000,000 lbs. at 5 cts.	"	4,900,000
Vegetables		"	50,000,000
Tobacco	483,000,000 lbs. at 9 cts.	"	42,000,000
Cotton	6,500,000 bales (480 lbs.)	"	250,000,000
Wool	300,000,000 lbs. at 15 cts.	"	45,000,000
Hay	45,000,000 tons at $8	"	360,000,000
Miscellaneous, including flax, flax-seed, hemp, grass-seed, garden seeds, wines, nursery products, etc., valued at			408,945,000

The mean percentage of ash or mineral matter contained in the most important of these products is as follows:

Wheat	2.06	Hay	7.24
Maize	1.55	Cotton stalks	3.10
Oats	3.18	Straw of wheat	5.37
Barley	2.89	" rye	4.79
Rye	2.09	" barley	4.80
Buckwheat	1.37	" oats	4.70
Rice	0.39	" buckwheat	6.15
Potatoes	3.77	Stalks of maize	4.87

The approximate quantities of mineral matters taken from the soil by a single crop of the cereals would thus be:

GRAIN.

	Wt. in lbs.	*% Ash.*	*Wt. Ash in lbs.*
Wheat	27,000,000,000	2.06	556,200,000
Maize	106,400,000,000	1.55	1,649,200,000
Oats	19,200,000,000	3.18	610,560,000
Barley	2,880,000,000	2.89	83,232,000
Rye	1,400,000,000	2.09	29,260,000
Buckwheat	650,000,000	1.37	8,905,000
Total			2,937,357,000

STRAW.

	Wt. in lbs.	*% Ash.*	*Wt. Ash in lbs.*
Wheat	45,378,000,000	5.37	2,436,798,600
Maize	212,800,000,000	4.87	10,363,360,000
Oats	32,000,000,000	4.70	1,504,000,000

	Wt. in lbs.	*% Ash.*	*Wt. Ash in lbs.*
Barley	4,800,000,000	4.80	230,400,000
Rye	2,333,000,000	4.79	111,750,700
Buckwheat	1,083,000,000	6.15	66,604,500
Total			14,712,913,800

The total weight of ash in the whole cereal production of the country is therefore—

In grain	2,937,357,000 pounds
In straw	14,712,913,800 "
Total	17,650,270,800 "

Since it is our intention to limit the scope of this work to phosphates, we may neglect all other constituents of the above amounts of ash, and confine our attention to the

QUANTITY OF PHOSPHORIC ACID YEARLY REMOVED FROM THE SOIL IN THE UNITED STATES.

GRAIN.

	Wt. Ash in lbs.	*% Phosphoric Acid.*	*Wt. Phosphoric Acid in lbs.*
Wheat	556,200,000	46.98	261,302,760
Maize	1,649,200,000	45.00	742,140,000
Oats	610,560,000	23.02	140,550,912
Barley	83,232,000	32.82	27,316,742
Rye	29,260,000	46.93	13,731,718
Buckwheat	8,905,000	48.67	4,334,063
Total			1,189,376,195

STRAW.

	Wt. Ash in lbs.	*% Phosphoric Acid.*	*Wt. Phosphoric Acid in lbs.*
Wheat	2,436,798,600	4.81	117,210,012
Maize	10,363,360,000	12.66	1,312,001,376
Oats	1,504,000,000	4.69	70,537,600
Barley	230,400,000	4.48	10,321,920
Rye	111,750,700	6.46	7,219,095
Buckwheat	66,604,500	11.89	7,919,275
Total			1,525,209,278
Total weight of the phosphoric acid in grain			1,189,376,195
Grand total, pounds			2,714,585,473

The acreage under cultivation for the production of the above cereals is estimated officially as follows:

Wheat	40,000,000	acres
Maize	75,000,000	"
Oats	23,000,000	"
Barley	2,500,000	"
Rye	1,800,000	"
Buckwheat	900,000	"
Total	143,200,000	"

The quantity of phosphoric acid per acre is therefore, for the whole cereal crop :

$$2,714,585,473 \div 143,200,000 = 19.0 \text{ pounds.}$$

For the hay crop a similar estimate may be made of the quantities of plant food removed.

The mean percentage of ash in the grasses of the United States is 7.97 ; for timothy it is 5.88 ; for clover it is 6.83. The mean content of ash may consequently be taken at 6.89 per cent. The total weight of hay produced, multiplied by this number, gives 6,201,000,000 pounds as the total weight of ash in the hay crop of the United States.

For the ash of timothy the percentage of phosphoric acid is 8.42 ; for red clover, 6.74. The mean percentage of phosphoric acid in the ash of timothy and clover is, therefore, 7.56.

The total weight of phosphoric acid in the hay crop therefore is

$$6,201,000,000 \times \frac{7.56}{100} = 468,795,600 \text{ pounds.}$$

The number of acres harvested in the United States is about 37,500,000, and the quantity of phosphoric acid removed per acre is consequently

$$468,795,600 \div 37,500,000 = 12.5 \text{ pounds.}$$

CHAPTER II.

PHOSPHATES AND THEIR ASSIMILABILITY.

In the spring-time phosphates are found in noteworthy quantities in young organs of plants, especially in the leaves, but the quantity gradually diminishes as the plant approaches maturity, until when the blossoms appear the phosphates are found to have entirely quitted the leaves and accumulated in the seeds. This is the cause of that peculiar effect, which has long puzzled farmers, that fodder cut and brought in *after the period of maturity* proves to be much less nourishing to the cattle than that cut before this period has arrived.

It is worthy of note that in every instance this displacement of the phosphates is accompanied by an equal displacement of the nitrogen, and all those who have made successive analyses of grains in different stages of maturity, must have been struck by the regular parallel manner in which the quantities of both have progressively augmented.

Mr. Corenwinder, alluding to this migration of phosphorus in vegetables, remarks:

"It has long been known that young buds are rich in nitrogenous matters, which are always accompanied by a relatively considerable portion of phosphorus, and there is no doubt that these two elements are united in the vegetable kingdom according to some mode of combination which is yet a mystery."

And Mr. Boussingault, writing upon the same subject, says:

"We perceive a certain constant relation between the proportions of nitrogen and phosphoric acid contained in foods, those being richest in the latter element which contain most nitrogen. This would appear to indicate that in the vegetable organization phosphates particularly cling to the nitrogenous principles, and that they follow the latter into the organization of animals."

The absolute necessity for the presence of phosphoric acid in the soil needs no further discussion. It is admitted on all hands that in its absence, vegetation, even when abundantly supplied with nitrogen and all other necessary elements, must come to a standstill.

The form in which it is assimilated is that of phosphate, produced by the combination of the acid with various bases. Enormous deposits of phosphate, chiefly of phosphate of lime, have been and doubtless will continue to be discovered in every quarter of the globe; and as, besides being so essential to plant life, it is the principal constituent of bones, we have here another proof that if by some extraordinary phenomenon its source were suddenly cut off or exhausted, all vegetable and animal life would cease.

So far back as the year 1698 a celebrated French engineer (Vauban), writing in the *Dime Royal*, said:

"We have for a long time past been universally complaining of the falling off in the quantity and quality of our crops; our farms are no longer giving us the returns we were accustomed to; yet few persons are taking the pains to examine into the causes of this diminution, which will become more and more formidable unless proper remedies are discovered and applied."

This was a warning note, but it was not until after the commencement of the present century that the English farmers began to use crushed bones as a manure, and even then they did so in blind ignorance of the principles to which they owed their virtues, as is clearly shown by an article published by one of the scientific papers of that day (1830), in which the writer says:

"We need take into no account the earthy matters or phosphate of lime contained in the bones, because as it is indestructible and insoluble it cannot serve as a manure, even though it is placed in a damp soil with a combination of circumstances analytically stronger than any of the processes known to organic chemistry."

A subsequent writer upon the same subject declares that "bones, after having undergone a certain process of natural fermentation, contain no more than *two per cent. of gelatine*, and as they derive their fertilizing power from this substance only, they may be considered as having no value as manure."

That such opinions as these should have prevailed only fifty years ago seems to us all the more preposterous because of the gigantic strides which we have made since then and because of the singular fact that even the Chinese were better informed than our grandfathers, inasmuch as they knew that the fertilizer was a mineral principle, and for many centuries have used burnt bones as manures.

Despite the unflagging researches of the best men of the time,

it was not until the year 1843 that the Duke of Richmond, after an exhaustive series of experiments upon the soil with both fresh and degelatinized bones, came to the conclusion that they owed their value not to gelatine or fatty matters, *but to their large percentage of phosphoric acid!* The spark thus emitted soon spread into a flame, and conclusive experiments shortly after published by the illustrious Boussingault set all uncertainty at rest forever

Numerous species of vegetables were planted in burnt sand, which was ascertained by analyses to contain no trace of phosphoric acid. It was, however, made rich in every other element of fertility. *No development of these plants took place until phosphate of lime had been added to the sand, but after this addition their growth became flourishing!*

Meanwhile large workable deposits of mineral phosphates were already known to exist, they having been almost simultaneously discovered in their respective countries by Buckland in England Berthier in France, and Holmes in America; and in the course of a lecture delivered to the British Association in 1845, Professor Henslow, describing the Suffolk coprolites, suggested the immense value of their application to agriculture. From this time may be dated the development of phosphate-mining as an industry, the pursuit of which has proved so remunerative to capital and labor.

The mode of occurrence of the best known deposits of phosphate of lime may well be termed eccentric. They have been found in rocks of all ages and of nearly every texture. Sometimes they are very pure, sometimes their combinations are extremely variable. Here they are found in veins, there in pockets, and here again in stratified layers or beds in connection with fossilized *débris* of all kinds deposited by the ancient seas. Apart from the deposits of the American continent, England, France, Germany, Belgium, Spain, Portugal, Norway, Russia, the West Indies, Tunis and Algeria, all have workable and more or less productive phosphate mines, some idea of which may be gathered from the following analyses:

TABLE SHOWING THE GENERAL AVERAGE COMPOSITION OF SOME OF THE MOST IMPORTANT PHOSPHATES.

	SPANISH AND PORTUGUESE.	NAVASSA.	ARUBA.	CURACOA.	GERMAN.	FRENCH ARDENNES.	MEXILLONES GUANO.	CAMBRIDGE COPROLITES.	NORWAY APATITES.	RUSSIAN COPROLITES.	SOMME, FRANCE.	BELGIAN (AVERAGE) CALCINED.
Moisture	1.20	5.73	1.53	0.75	1.27	5.20	10.90	1.24	0.47	5.10	2.00	0.25
Water of combination	3.60	4.93	5.03	1.07	2.17		11.01	2.40	0.36		1.02	
*Phosphoric acid	32.36	31.69	35.77	39.62	29.99	23.45	33.70	26.85	42.34	27.48	35.70	20.59
Lime	47.28	38.00	47.62	50.04	42.20	40.48	28.00	42.96	51.63	43.00	51.20	52.50
Carbonic acid	3.20	2.40	1.89	7.55	4.15	4.83	3.70	7.06	5.20	4.60	4.10	5 55
Oxide of iron	1.93	4.25	2.05	traces	5.15	2.97	Various undetermined. 8.01	4.16		3.40	1.40	18.61
Alumina	1.03	8.81	1.54	0.45	0.12	2.15		3.01		1.09	0.70	
Sulphuric acid	traces	1.10	1.70	traces	traces	1.30		0.76		1.04	0.76	.....
Fluorine	2.87		1.72	traces	1.71	0.94		1.15		0.47	1.92	.....
Insoluble siliceous matters	6.53	3.09	1.15	0.52	13.24	18.68	4.68	10.41		13.82	1.20	2.50
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
*Equal to tribasic phosphate of lime	70.55	69.85	79.08	86.37	65.40	51.22	73.45	58.53	92.30	59.97	78.50	45.30

Very large deposits of phosphates of alumina and iron have been discovered in the islands of Redonda and Alta Vela, and were at first mistaken and shipped in large quantities for phosphate of lime. Upon complete analysis in London, however, their true nature was discovered, and being quite unsuitable for the manufacture of superphosphate, they were denounced by leading agricultural chemists as valueless for fertilizer purposes. The cargoes were consequently refused by the consignees and thrown upon the market at very low prices; and so great was the prejudice against them that a long time elapsed before they met with any purchasers. The detailed composition of these phosphates is shown in the following analysis, made by us from a fair and well-selected sample:

Moisture	12.36
Water of combination	4.13
* Phosphoric acid	30.22
Lime	4.16
Magnesia	traces
Oxide of iron	7.04
Alumina	24.00
Carbonic acid	None
Sulphuric acid	"
Fluorine	traces
Insoluble sandy matter	18.09
	100.00

* Equal to 65.87 per cent. of tribasic phosphate of lime.

It appears to have been forgotten, overlooked, or ignored, by the opponents of these phosphates that the phosphoric acid in the soil invariably exists in the form of phosphates of iron and alumina. The so-called experts had probably not then learned what they are now compelled to admit, that although some difficulty may attend their decomposition in the factory or their transformation into chemical fertilizers, these phosphates are extremely valuable in the raw state—if very finely ground—as a direct manure.

Nor is this a matter of any personal opinion or prejudice, for as we and others have frequently shown, the iron and alumina in the soils exercise an immediate transforming action upon the phosphate of lime introduced into them in both natural and artificial forms.

Any one can demonstrate this transformation by adding either peroxide of iron or alumina, or both, to a solution of lime phosphates in water charged with carbonic-acid gas (ordinary car-

bonated water at high pressure), when in a very short time all phosphoric acid will have disappeared from the solution and will be found in the deposit as phosphate of iron and alumina.

If the chemists alluded to had confined their statements to the fact that phosphates of iron and alumina were not advantageous materials for the manure manufacturer, they would have been perfectly correct; but they took on themselves a vast responsibility when they declared them to be useless as fertilizers, for of all questions, that as to the form in which phosphoric acid offers the best all-round advantage to the practical farmer is the most subtle and most delicate.

If we accept the generally-admitted and rational theory that no element can penetrate into the interior of a plant unless it be in solution, it naturally follows that preference will be invariably given to those commercial phosphates which are most readily subject to dissociation; and this will entirely depend upon two conditions:

(*a*) Their own degree of aggregation.

(*b*) The nature and composition of the soil in which they are employed.

The first thing to be obtained is undoubtedly a fineness of pulverization which will so divide the molecules as to render them easily decomposable by the natural action of the elements contained in the ground. Here we touch at once the real source of our difficulty, for in the matter of pulverization only partial success has so far been achieved by any sufficiently cheap mechanical means, and we are not very much further forward now than we were in 1857, when Liebig recognized the difficulty and proposed, in order to solve it, to chemically perform the disintegration by manufacturing superphosphates.

From the standpoint of disintegration this method of Liebig's has been entirely satisfactory, and has enabled agriculture to rapidly obtain results from the use of phosphoric acid which would otherwise have been impossible. From a chemical point of view, however, the whole theory fails. We have seen that superphosphates are only soluble in water so long as the sulphuric acid with which they have been manufactured retains its ascendency, and that when they reach the soil, especially where carbonates are in abundance, the sulphuric acid is at once overpowered, and the phosphoric acid, instead of remaining combined with one molecule of lime and two molecules of water, at once undergoes reversion. To put it plainly, the issue revolves upon a matter of time and of

money. The farmer buys a ton of raw phosphates, ground as finely as possible and containing, let us say, twenty-five per cent. of phosphoric acid, for $10. If his land be tolerably acid he will get a rapid return, but if it be not, the phosphate will not decompose, and he will have to wait perhaps several years before obtaining any appreciable results for his outlay. On the other hand, he buys a ton of superphosphates, containing only fourteen per cent. of phosphoric acid, for $20, and applying it to a phosphate-barren soil, produces the desired results on his very next crop. Hence it is apparent that the phosphoric acid of the latter is more readily *assimilable* than that of the former case; and this assimilability can only be due to its absolute state of division, which enables the phosphate to come into contact with the acid sap of a greater number of root hairs and thus to be dissolved and absorbed by the plant. We therefore repeat, that to define with scientific accuracy the exact merit or intrinsic value of any specific phosphate is a matter of very serious difficulty; since besides that of its own physical condition, so much depends upon the nature and composition of the soil in which it is to be employed.

Dr. Charles Graham, of University College, London, was one of the first to realize the facts we have noted, and writing upon the subject some ten years ago, said that "the vitriolating process, whereby soluble phosphate is formed, was of value where nothing but bones was employed, since it gave agriculture a convenient means of distributing over the land an easily soluble substance in the place of the pieces of bone previously used. With coprolites the same thing was supposed to hold, and as years rolled on acid was more and more used in the preparation of phosphatic materials, until at last these have become rather vitriol-carriers to the profit of the manure manufacturer than to the benefit of agriculture. Analytical chemists attached so high a value to the soluble phosphates that the factor 30 became with many the multiplier in calculating the commercial value from the centesimal composition of the superphosphates. Some, indeed, went beyond this; and in time analytical chemists came to think of soluble phosphates as the only test of vitriolated phosphate minerals—the insoluble being regarded as of little or no use."

The same subject received much attention at the International Congress of the Directors of Agricultural Experimental Stations, held in Paris in June, 1881, and the result was a general approval of the efficacy of the undissolved forms.

It appears to be established by the record of this congress that French and German agricultural chemists are now in accord in regard to the comparative value of *soluble* and *precipitated* phosphates (*i.e.*, those which had once been soluble but have returned to the insoluble state in fine division), French chemists having held for some time that they should be on an equal footing. They also assented to the value of raw ground phosphate of lime, and declared that

"The congress is of opinion that in reports of analyses the directors of stations should state the solubility of phosphates by the expressions 'phosphoric acid soluble in cold citrate of ammonia' or 'soluble in water,' and not that of 'assimilable phosphoric acid;' the Congress believing that to apply the term assimilable to the phosphate soluble in the citrate would be to class implicitly and necessarily in the category of substances not assimilable, the phosphates which are evidently soluble in the soil, such as those in bone ash, guano, bone powder, farm-yard manure and fossil phosphates."

There is probably not a single one of our agricultural experiment stations in which the assimilability of raw mineral phosphates finely ground has not been the object of intelligent study, but so far as we have been able to ascertain by diligent inquiry up to date, the results have varied, as we have already premised, in accordance with the kind of phosphate used and the nature of the soil into which they were introduced. Nothing of any serious moment has in fact occurred to modify the conclusions formulated in 1857 by the well-known Frenchman, De Molon, who, reporting on a very extensive series of trials of ground raw coprolite in many different departments of France, said that

1. It might be used with advantage in clayey, schistous, granitic and sandy soils rich in organic matter.

2. If these soils were deficient in organic matter or had long been under cultivation, it might still be used in combination with animal manure.

3. It may not be used with advantage in chalky or limestone soils.

Here, as it strikes us, is a fairly representative case where an intelligent discrimination is demanded of the farmer, and where he must realize that the term *soluble* as applied to phosphate fertilizers is an entirely relative one. In one portion of his lands he may use raw phosphates, and they will prove to be soluble and produce

excellent results; in another portion, owing to different constitution of the soil, they will remain insoluble and the result will be *nil.*

In England and in some parts of Germany it is still the custom, as we shall show later on, to base the commercial value of a manufactured phosphatic material almost entirely upon its percentage of phosphoric acid soluble in cold water, and to allow little or nothing for that which may exist in the "reverted" or water-insoluble form. As shown by our experiments and demonstrated by our practice in this country, however, the latter is entirely assimilable by plants, and should therefore have a commercial value approximately equal to that of the water-soluble phosphate.

Neither English nor German chemists worthy of that name attempt to deny this fact, but they appear to be in advance of the philosophy of their lay contemporaries and have not yet acquired sufficient power to stamp out prejudice and imposition.

All newly discovered truths, when first communicated to an unprepared society, are first denounced and then put aside and forgotten by the vast majority; but by and by, when a generation or two have passed away, we see those very truths, so long considered as without the pale of human possibilities, insensibly come to be looked upon as commonplaces which even the dullest intellects wonder how we could ever have denied.

Men may come and men may go, but science remains behind. It sustains the shock of empires, outlives the struggles of rival theories and creeds, and, built upon a rock, must stand forever.

How, then, can we expect the farmers to perpetually remain in ignorance or darkness on this question, when we know that they are becoming less and less able to restore to their soils, in any other form than that of phosphate of lime the phosphoric acid taken from them year by year with their crops?

Nothing can stem the demand for artificial manures; it will go on increasing with such steadiness and rapidity that the visible sources of supply will soon become inadequate. Especially is this true of phosphates of lime, and the recognition of this fact by those engaged in the fertilizer industry explains the eagerness with which fresh deposits of the material are being sought for all the world over.

The vast workable deposits of the American continent are just at this moment the centres of attraction, and it will therefore be interesting to a large section of the public to know something

about the mode of their occurrence, how they are mined, handled, prepared for the market, and what they cost. All this information we shall endeavor to convey in as brief a manner as may be consistent with lucidity, and we shall add to it a practical description of the manufacture of sulphuric acid, superphosphates and "high grade supers," and shall give a general outline of those methods of analyses shown by our long and varied experience to be best suited to each class of product.

At the present time there is a great and regrettable divergency in the results of phosphate analyses made by different chemists. To the uninitiated this is an unaccountable fact, to be explained only by a very excusable and popular conclusion, that analytical chemistry is not a reliable or exact science, and that it cannot produce in practice what it expresses by equation. Why, it is asked, should the chemist in the South—who is perfectly conscientious and who has no interest to deceive—differ materially in his findings from a chemist equally but no more honest and trustworthy working at the East or North? This is a consistent question, and it demands a prompt solution.

Nothing could cast a greater aspersion on the highest of professions than this state of affairs, and yet nothing on earth could be more easily and perfectly remedied. All that is necessary is for chemists to come together and agree upon certain methods, and to invite purchasers and sellers of phosphates and manures to regulate their settlements on a *prescribed basis.* In this manner all divergency of results should disappear, and, all other conditions being equal, any further discrepancies would be attributable only to incompetency or bad faith. The hand, of course, is not always steady, nor is the eye always accurate, and while we are liable to physical defects and weaknesses, we shall never be free from mistakes; but it is nevertheless a fact which has forced itself upon all thinking men, that uniformity in manipulation is the prime factor in the attainment of uniform results, and nowhere is such uniformity a *sine qua non* as in the laboratory.

CHAPTER III.

THE PHOSPHATES OF NORTH AMERICA.

THE greatest of our geologists have agreed upon dividing the earth's crust into four classes or periods, which they have named respectively the *Archæan, Paleozoic, Mesozoic* and *Cenozoic* times, and the phosphates which we are now to describe occur in the rocks of the first of these divisions, in that portion of them known as the Gneiss formation or Laurentian period.

These rocks are made up almost entirely of pyroxene, calcite, hornblende, mica, fluor-spar, quartz and orthoclase, and are more or less intermixed at various points with apatite, pyrites, graphite, garnet, epidate, idocrase, tourmaline, titanite, zircon, opal, calcedony, albite, scapolite, wilsonite, steatite, chlorite, prehnite, chabasite, galena, sphalerite, molybdenite, etc.

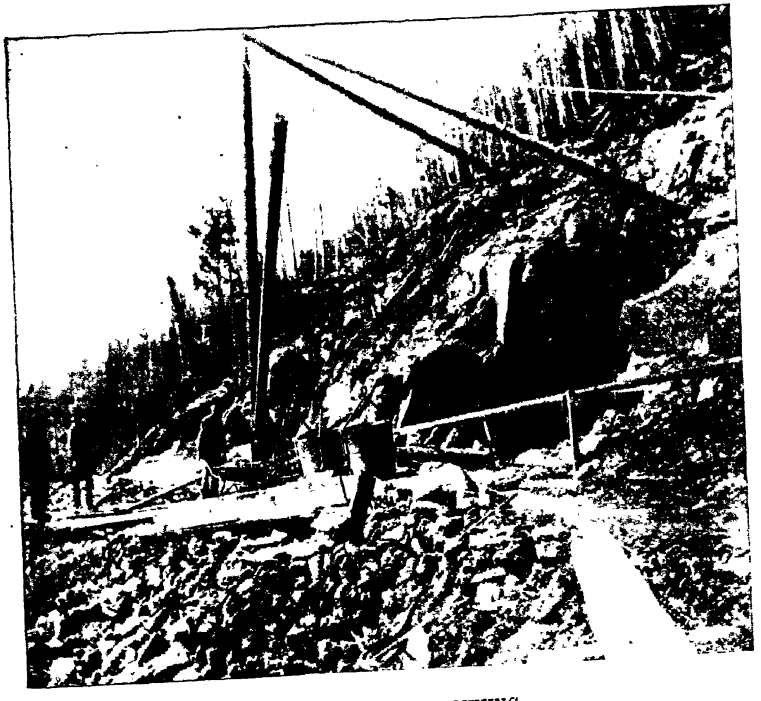
The two districts in Canada in which apatite has been thus far found to exist in workable quantities are Ottawa County, in the province of Quebec, and Leeds, Lanark, Frontenac, Addington and Renfrew Counties, in the Province of Ontario. The latter district, therefore, covers a much larger area than the former, but on the other hand the country is much lower, the rocks more hornblendic and the apatite much more "pockety" and scattered. In both districts the Laurentian rocks form immense belts, which traverse the country for many miles with a N. E. and S. W. trend, and which, according to Dana, Hunt and other investigators, extend downward to a depth of at least twenty-five or thirty thousand feet. There is, as may be readily inferred, a great variability in their composition. Sometimes they are entirely granitic gneiss, hornblendic gneiss, rust-colored gneiss and brownish quartz; at others they are made up of pyroxene, feldspar, calcite, mica, apatite, and pyrites. While there are undoubtedly many spots in which the apatite would appear to occur in true veins of extreme purity, we have found that the general formation of the fissure material is that of a series of conglomerates. In other words, the gigantic lodes are a mixture in which the predominance alternates between pure apatite and pyroxenite or mica, or feldspar, or, in fact, any other of the minerals already enumerated.

The lodes themselves, however, are nevertheless very strongly defined, and there can be no doubt at all as to their continuity in depth. In the province of Quebec we have followed them over the townships of Hull, Templeton, Buckingham, Wakefield, Portland, Derry, Denholm, Bowman and many others, farther north and west, and they everywhere exhibit the same characteristics. Sometimes they contain no apatite; at others it is only present in rare disseminated crystals. Sometimes they contain it in the proportion of from ten to fifteen per cent. of their entire mass over a very large area. Sometimes, again, it displaces the other rocks altogether, and develops into enormous "bonanzas," in which scarcely any impurities are found.

The principal phosphate mines of Canada have been located on those portions of the pyroxenite belt in which, at the surface, the apatite has shown signs of predominating, and it is on record that, so far as explored, when these surface "shows" exist in association with feldspar, mica or pyrites, the apatite has always continued downward with variable regularity through the entire formation. By far the greater part of the phosphate mined of late years has been obtained in the Quebec district, chiefly from that portion of Ottawa County through which flows the Lièvres River. This fact is demonstrable by a reference to the following table, compiled with great care from official data.

COMPANIES WORKING APATITE MINES IN CANADA IN 1891.

NAME OF COMPANY.	CAPITAL.	DISTRICT WHERE WORKING.	DAILY AVERAGE OF MEN EMPLOYED
Anglo-Canadian Phosphate Co., L'd	$500,000	Perth, Ontario.	45
Anglo-Continental GuanoWorks Co	800,000	Lièvres River, Quebec.	100
Canadian Phosphate Company.....	550,000	" "	150
Central Lake Mining Co.....	Private capitalists.	" "	20
Dominion Phosphate and Mining Co	125,000	" "	50
Dominion Phosphate Co., L'd, of London.....	200,000	" "	50
East Templeton District Phosphate Mining Syndicate.....	30,000	Templeton, Quebec.	100
Foxton Mining Company, L'd.....	60,000	Kingston, Ont.	75
Frontenac Phosphate Company	50,000	" "	30
Kingston Mining Co	25,000	" "	30
Little Rapids Mining Co	Private capitalists.	Lièvres River, Quebec.	15



CANADIAN APATITE-MINING.

Open cut in pyroxene rock worked by steam derrick, High Falls Mine, Ottawa Co.

Companies working Apatite mines in Canada in 1891.—*Continued.*

NAME OF COMPANY.	CAPITAL.	DISTRICT WHERE WORKING.	DAILY AVERAGE OF MEN EMPLOYED
MacLaurin Phosphate Mining Syndicate	100,000	Templeton, Quebec.	50
Ottawa Mining Co	Private capitalists.	Lièvres River, Quebec.	25
The General Phosphate Corporation, L'd	1,000,000	" "	250
Phosphate of Lime Co., L'd	250,000	" "	200
Sydenham Mica and Mining Co	250,000	Kingston, Ont.	25

It is affirmed by some excellent authorities that pyroxene rock is never found distinctly bedded, though occasionally a series of parallel lines can be traced through it, which, while possibly the remains of stratification, are probably often joint planes. Sometimes, when the pyroxenite has been weathered, apparent signs of bedding are brought out, which are often parallel to the bedding of the country-rock. Thus at Bob's Lake mine, in Frontenac County, a rich green pyroxenite occurs which exhibits this structure. For 10 feet down from the surface this apparent bedding can be distinguished. It gradually grows fainter, until it disappears in the massive pyroxenite below. A similar phenomenon has been observed at the Emerald mine, Buckingham Township, Ottawa County, Quebec, and at several other places.

The pyroxene occurs in several different forms. Sometimes it is massive, of a light or dark green color, and opaque or translucent; at other times it is granular and easily crumbled. Occasionally it occurs in a distinctly crystalline form, the crystals being in color of different shades of a dull green, generally opaque or translucent, but sometimes, though rarely, almost transparent. The massive variety is the most common and composes the greater part of the pyroxenites found in the phosphate districts.

The associated feldspar is generally a crystalline orthoclase, varying in color from white to pink and lilac, but occasionally it occurs as a whitish-brown finely crystalline rock. The trap is of the dark, almost black, variety. The apatite itself occurs, as we have already explained, in a very capricious manner and in a very great variety of forms.

The first Canadian phosphate-mining was done in the township of North Burgess, in Lanark County, and about the year 1863 extensive investments were made in lands in that township, near the Rideau Canal, as high as $300 per acre having in some cases

been paid. In 1872 mining was begun on the Lièvres River and gradually increased until 1880, when English and American capitalists embarked in the industry and prosecuted work on a large scale with the aid of steam machinery. Previous to this time hand labor only was employed and a good proportion of the output was obtained by farmers, who discovered the mineral on their lands and worked at it in a desultory manner as attention to their farm duties permitted.

The result of such a method was, of course, that the whole of a property was soon cut up with small pits and trenches, rarely exceeding 20 feet in depth, and often interfering considerably with later and larger mining operations, and it was not until well-organized companies, directed by efficient engineers, with steel drills, hoists, pumps, etc., came into the field, that the exploitation proceeded on a sound basis. It would be impossible and at the same time uninteresting to attempt a detailed description of all the mines that have been operated, and we have concluded to content ourselves by selecting one of the best as a typical example.

For this purpose we will describe the mode of occurrence, method of working, possibilities of production and qualities of product at the *North Star Mine*, which is situated on the east bank of the Lièvres River, in the township of Portland, and which in our opinion is one of the very few enterprises of its kind which have been conducted on true mining principles. It is perhaps the only one in which proper development work has been undertaken with a view rather to lasting profits than immediate and temporary gains. The managers have made themselves acquainted with and have thoroughly understood the peculiar nature of the formation with which they have had to deal. They have consequently divided their work from the commencement of their operations into two distinct phases, exploration and exploitation.

The first has consisted in prospecting the lode or belt, uncovering its surface over the entire property, to prove the continued presence of the apatite, and then in opening up pits or quarries to a sufficient depth to demonstrate the importance, dimensions and trend of the deposit.

The second has consisted in simply following up the indications thus laid bare, by sinking shafts upon the vein, in conformity with the strike and dip of the phosphate.

The results of this policy have been manifold. Scientifically they have taught us all we now know concerning the mode of oc-

CANADIAN APATITE-MINING.

Open quarrying in pyroxenite conglomerate by means of steam drills. The apatite is mixed up heterogeneously with the other rocks in the average proportion of about seven per cent.
Ross Mountain, Lievres River, Ottawa Co.

currence and the continuity in depth of Canadian apatites. Industrially they have secured to the company some very considerable reserves of phosphate, which are now in sight and ready for extraction.

The entire property consists of 200 acres, and it is traversed throughout its length by the pyroxene belt or band, which contains, besides the apatite, a large number of the characteristic minerals and has an average width of some 250 feet. The pyroxene is occasionally intermixed at the surface with bowlders of granite or gneiss. The trend of the belt or vein is in the usual northeasterly and southwesterly direction, and at intervals of from 50 to 75 feet it is intersected from east to west by faults, or chutes, which dip to the south at an angle of from 45° to 60°, and as these all contain an abundance of apatite they have been chosen as the fitting points for sinking shafts and pits.

Taking the southern boundary as a point of departure, the belt of phosphate-bearing matter has been prospected and proved by openings practised at intervals of from 25 to 50 feet.

Proceeding along the vein towards the north for about 500 feet, we reach the first important opening sunk upon it and known as

The Office Pit, a species of quarry 150 feet in length by 40 in width and about 35 feet deep. Here we find the usual masses of characteristic conglomerates, mica, feldspar and apatite alternating in predominance or heterogeneously mixed up together. In the west-end corner of the quarry a small pit, some 6 feet square, has been sunk upon a vein of apatite and has shown the same features to continue in depth. From a careful measurement and comparison of the entire matter in place, the proportion of pure apatite in this portion of the lode is estimated at eight per cent. of the total material to be removed. In other words, for every 100 tons of rock removed 8 tons of apatite can be secured.

The next in line, at a distance of 100 feet, is the

Alice Pit No. 1, an opening 25 x 15 and 10 feet deep. Here, in exactly the same formation as the preceding, there is a very fine vein of pure apatite, about 12 feet wide, running down from the surface with the usual dip to the south.

Following the belt for another 60 feet we come to

Alice Pit No. 2, which has been opened up for a depth of 10 feet on a fault in the vein 30 feet long by 15 feet wide. Several small veins, or *stringers*, of apatite imbedded in the usual conglomerate have merged into one, which has gradually widened out until at the bottom it has attained about 5 feet. This is an

excellent prospect, with all the appearance of developing into a bonanza when brought into further working order.

Passing over several other openings and faults of similar character for about 250 feet, we come to

Pit No. 3, which is now being developed and got into shape for exploitation. It has been sunk in solid vein matter and upon the dip of the chute to a depth of about 100 feet and still retains the appearance of an open quarry. Down its southwest side there run three well-defined veins of apatite, each of them occasionally interspersed with or hidden from sight by bowlders of feldspar, mica, calcite and pyroxene.

The next opening upon the belt is at a distance of only 50 feet and is known as

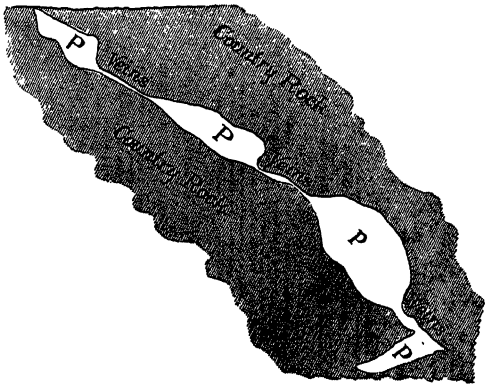
Shaft No. 1. It is sunk on the dip of the vein at an average angle of about 55° and is now about 600 feet deep. Its progress has been watched with the greatest interest by all who are in any way connected with or concerned in the apatite-mining industry, and it has served to prove beyond contestation that the sought-for material is not confined to a mere superficial stratum, but that it continues to accompany the other minerals with which it is so intimately associated, in exactly the same manner, in depth as at the surface. The same mixture of rocks, the same conglomerates, the same alternating preponderances—these are the history of the shaft.

Small veins or strings of apatite led into enormous pockets or bonanzas, yielding many thousand tons of pure phosphate; these, in course of time, gradually pinched out and were replaced by pyroxene, feldspar or mica, through which the veins of apatite were followed until they again merged into a preponderating mass.

At the time of our visit to the mine the shaft contained a great deal of water, which had drained in from the melting of the last winter's snow, but the managers were good enough to have the water pumped out in order to facilitate our inspection, and we were thus able to descend in it to within 50 feet of the bottom. After careful inspection, we became satisfied that there are very large reserves of apatite in the shaft, especially as the bottom is neared, and that it can readily be mined and brought to the surface.

Under the peculiar circumstances of the geological formation it was impossible to sink this shaft with any great degree of regu-

larity. The run of the apatite is a capricious one, and was found to shift about from side to side and take the place of other rocks in a manner that baffled all calculations. We may, perhaps, better convey our meaning if we liken its occurrence to a long string of sausages, of very irregular shape and divided by very irregular lengths of skin, say, for instance, thus :



These pockets were of course worked out as they occurred, with the result that the interior of the shaft now presents the appearance of a series of immense caverns alternating with narrow passages or tunnels. So far as it was possible to judge from the present appearance of the shaft and of the dumps by which it is surrounded, we estimated the amount of rock material already removed from it at about 160,000 tons and the apatite at about twelve per cent. of that total.

At a distance of 100 feet further along the belt we reach

The Shaft No. 2, a reproduction in the main of the No. 1 shaft already described. It has been carried down on the dip of the vein at an angle of 50° to 55° S. with a tramway which hugs the foot-wall. The width and height of the shaft range from 50 to 120 feet wide and from 16 to 75 feet high, all in solid vein matter between well-defined walls of granitic gneiss, with phosphate overhead and underfoot. The apatite in the vein has frequently developed into large bonanza chambers or pockets, and there is every promise of a continuation of this phenomenon as

the pit goes down, since the bottom and sides of it now consist almost entirely of massive green phosphate. From careful measurements in the excavation, the quantity of total material removed from this shaft was computed at about 40,000 tons and the proportion of apatite at about twelve per cent. of the mass. The average daily number of men employed in sinking this shaft and dealing with the ore has been as follows :

Twenty-five miners and strikers with 1 steam drill underground ; 5 men at the surface unloading the cars ; 25 men and boys in the cobbing-house, engine-house and blacksmith's shop ; total, 55 men and boys. The average wages paid to these—grouped together—has been $1 per capita and per day.

The average cost of powder and steam and the wear and tear of drills, engines, hoists, tools and other plant we estimate from practical experience at 25 cents per ton of rock removed.

From these data it is easy for us to compute the cost of the phosphate per ton.

55 men and boys at $1 per day for 300 days	$16,500
40,000 tons of rock removed at 25 cents per ton for plant and wear and tear	10,000
Total cost of, say, 5,000 tons clean phosphate	$26,500

or, say, $5.60 per ton at the mine.

The width of the pyroxene belt in the neighborhood of this shaft is about 300 feet, and saving that in some places there is a considerable intermixture of huge granitic bowlders, there is no change in its predominating characteristics over the remainder of the property.

The equipment necessary to the proper working of an apatite mine must include :

One or two good boilers of about 50 H. P. each.
One or two double drill compressors.
One or two hoisting engines of about 20 H. P. each.
Three or four machine drills fully equipped.
All necessary fittings and pipe for compressors.
A first-class plunger pump.
A first-class double forcing pump.
A line of transport wagons of about 2 tons each capacity.
A line of transport sleighs, for winter, of about 2 tons each capacity.
A commodious blacksmith and carpenter shop, well provided with all kinds of tools.
A cobbing-house fully equipped.

CANADIAN APATITE-MINING.

Drifting on apatite vein in pyroxene rock with steam drills, High Rock Mines, Buckingham, Que.

A cooking and boarding house to accommodate, say, 250 men.
A sleeping-house to accommodate, say, 250 men.
A large warehouse for stores of all kinds.
Offices and dwelling for a local superintendent.

It has already been explained that the form in which the phosphate occurs in the Canadian mines is that of a hexagonal crystalline mass of fluor-apatite. Sometimes it is extremely compact; at others it is coarse and granular. It has a hardness of 5 and a mean specific gravity of 3.20, and is generally so friable as to fall to pieces if struck with the pick. It varies in color from green to blue, red, brown or yellow, according to the greater or lesser proportions of impurities with which it is contaminated.

A series of our analyses made from average samples taken from many of the largest working mines may be regarded as very fairly representative of the average chemical composition of the material.

COMPOSITION OF COMMERCIAL SAMPLES OF CANADIAN APATITE.

	1st Qual.	*2d Qual.*	*3d Qual.*
Phosphate of lime	88.20	78.65	66.22
Carbonate of lime	4.13	8.05	9.20
Fluoride of lime	3.10	3.04	2.97
Alumina and iron oxides	0.70	1.03	1.37
Magnesia	0.20	0.31	0.47
Insoluble siliceous matter	3.67	8.92	19.77
	100.00	100.00	100.00

What is the origin of these remarkable phosphates is a question that has been, and still continues to be, the cause of much controversy.

Sir William Dawson, in a paper read before the Natural Historical Society, Montreal, 1878, "On the Phosphates of the Laurentian and Cambrian of Canada," discusses the probability of animal origin, and holds that there are certain considerations which point in this direction. Among these are the presence of the iron ores, the graphite, and of Eozoon Canadense, which he, with others, holds to represent the earliest known forms of life. He further says that the possibility of the animal origin of this phosphate is strengthened by the presence of phosphatic matter in the crusts and skeletons of fossils of primordial age, "giving a presumption that in the still earlier Laurentian a similar preference for phosphatic matter may have existed and perhaps may have extended to still lower forms of life."

Others, again, have contended that it must have been ejected from the earth's interior by volcanic action, and prominent among these is the present Director of the Geological Survey of Canada, A. R. C. Selwyn, who says:

"My own examinations of the Canadian apatite deposits (veins, etc.) have led me to a conclusion respecting their origin corresponding with that of the Norwegian geologists. I hold that there is absolutely no evidence whatever of the organic origin of the apatite, or that the deposits have resulted from ordinary mechanical sedimentation processes. They are clearly connected, for the most part, with the basic eruptions of Archæan date."

This view is also taken by Mr. Eugene Coste, who, in his report on the "Mining and Mineral Statistics of Canada for 1887," concludes an article on "The Iron Ores and Phosphate Deposits (?) in the Archæan Rocks" by saying:

"It is only natural that we should conclude, as many other geologists have done before, that the iron ore and phosphate to be found in our Archæan rocks are the result of emanations which have accompanied or immediately followed the intrusions through these rocks of many varied kinds of igneous rocks which are no doubt the equivalent of the volcanic rocks of to-day. These deposits, then, are of a deep-seated origin, and consequently the fears entertained, principally by our phosphate miners, that their deposits are mere surface pockets, are not well founded. These fears are no doubt partly the result of the belief which has been somewhat prevalent that the apatite in them was the metamorphic equivalent of the phosphate nodules of younger formations, and it may be also that they have resulted from the fact that the apatite is irregularly distributed in these deposits and is often suddenly replaced by rock. But notwithstanding this, when the deposits are properly understood to be, as we hold they are, igneous dykes and veins accompanying the igneous rocks, it will be easily seen why in the deposit itself the economic minerals can be suddenly replaced by rocks which may be said to be nothing else but the gangue. If this origin is understood it will facilitate and encourage the working of these deposits in depth, because the accompanying igneous rock, forming a mass or a dyke alongside of the deposit, will be easy to follow, and because if it is apatite or iron-bearing at the surface, it will always be a guarantee that it will also be in depth, as each separate mass of igneous rock is generally quite constant in composition."

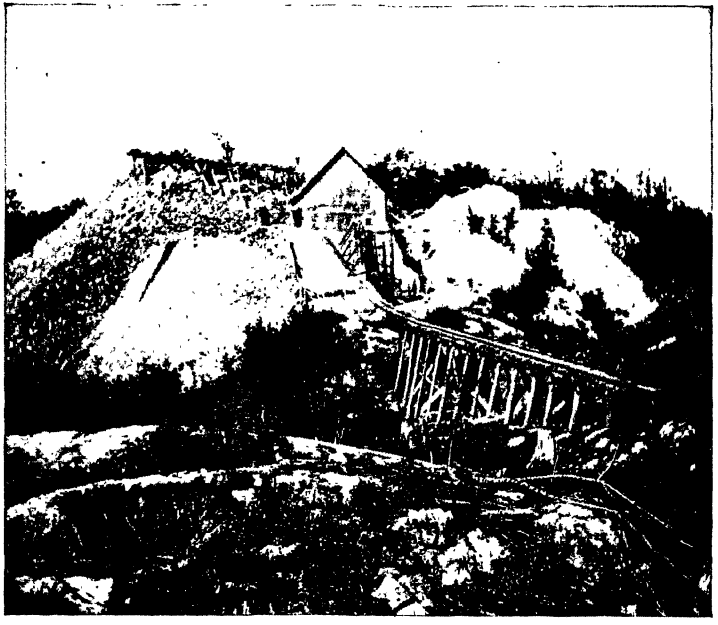
Despite the great attention and care with which we have ourselves examined numerous specimens of the Canadian apatites taken from various points over the entire formation, we have failed to discover by means of the microscope the least trace of anything that would lead us personally to connect them with organic life. We prefer to ascribe them to a decomposition of the pyroxenite by a process of segregation similar to that which in other places has resulted in the production of quartz and orthoclase, and we can see no reason for making any distinction between the character of the deposits. According to Dr. T. Sterry Hunt, the stratiform character of these endogenous deposits, as seen alike in the individual portions and in the arrangement of these as constituent parts of a vein, is well shown at the Union mine, in the Lièvres district. Here the great mass or lode is seen to be bounded on the west by a dark-colored amphibolic gneiss, nearly vertical in attitude, and with northwest strike. Within the vein, and near its western border, is enclosed a fragment of the gneiss, about twenty feet in width, which is traced some yards along the strike of the vein to a cliff, where it is lost from sight, its breadth being previously much diminished. It is a sharply broken mass of gray banded gneiss, with a re-entering angle, and its close contact with the surrounding and adherent coarsely granular pyroxenic veinstone is very distinct. Smaller masses of the same gneiss are also seen in the vein, which was observed for a breadth of about 150 feet across its strike (nearly coincident with that of the adjacent gneiss), and beyond was limited to the northeast by a considerable breadth of the same country-rock.

In one opening on this lode there are seen, in a section of forty feet of the banded veinstone, repeated layers of apatite, pyroxenite and a granitoid quartzo-feldspathic rock, including portions of dark brown foliated pyroxene, all three of these being unlike anything in the enclosing gneiss, but so distinctly banded as to be readily taken for country-rock by those not apprised of the venous character of the mass. A fracture, with a lateral displacement of two or three feet, is occupied by a granitic vein twelve inches wide, made up of quartz with two feldspars and black amphibole, which themselves present a distinctly banded arrangement. This same granitic vein is traced for fifty feet, cutting obliquely across both the pyroxenite and the older granitoid rock, and at length spreads out, and is confounded with a granitic mass interbedded in the greater vein. It is thus posterior alike to the older quartzo-feld-

spathic rock, the pyroxenite and the apatite, as are also many smaller quartzo-feldspathic veins, which, both here and in other localities in this region, intersect at various angles the apatite, the pyroxenite and the granitoid rock into which the latter graduates. We have thus included in these great apatite-bearing lodes quartzo-feldspathic rocks of at least two ages, both younger than the enclosing gneiss. A smaller vertical vein of fine-grained black diabase-like rock intersects the whole. No one looking for the first time at this section of forty feet, as exposed in the quarry, with its distinctly banded and alternating layers of pyroxenite and granitoid quartzo-feldspathic rock, including two larger and several smaller layers of crystalline apatite, would question the stratiform character of the mass, whose venous and endogenous nature is nevertheless distinctly apparent on further study.

In other portions of the same great vein, quarried at many points, this regularity of arrangement is less evident. Occasionally masses are met with presenting a concretionary structure, and consisting of rounded or oval aggregates of orthoclase and quartz, with small crystals of pyroxene around and between them; the arrangement of the elements presenting a radiated and zone-like structure, and recalling the orbicular diorite of Corsica. The diameter of these granitic concretions varies from half an inch to one and two inches, and they have been seen in several localities in the veins of this region over areas of many square feet.

In the Emerald mine the stratiform arrangement in the vein is remarkably displayed. Here, in the midst of a great breadth of apatite, were seen two parallel bands (since removed in mining) of pyroxenic rock, several yards in length, running with the strike of the vein, and in their broadest parts three and eight feet wide respectively, but becoming attenuated at either end and disappearing, one after the other, in length, as they did also in depth. These included vertical layers, evidently of contemporaneous origin with the enclosing apatite, were themselves banded with green and white from alternations of pyroxene of a feldspar with quartz. Accompanying the apatite in this mine are also bands of irregular masses of flesh-red calcite, sometimes two or three feet in breadth, including crystals of apatite, and others of dark-green amphibole. Elsewhere, as at the High Rock mine, tremolite is met with. In portions of the vein at the Emerald mine pyrite is found in considerable quantity, and occasionally forms layers many inches in



CANADIAN APATITE-MINING.

View of the "cobbing" house, "ore bins" and "dump" in the "Cap Rock Pit," High Rock Mines, Lievres River, Ottawa Co.

thickness. Several large parallel bands of apatite occur here with intervening layers of pyroxene and feldspathic rock, across a breadth of at least 250 feet of veinstone, besides numerous small irregular, lenticular masses of apatite. The pyroxenite in this lode, as elsewhere, includes in places large crystals of phlogopite, and also presents in drusy cavities crystals of a scapolite and occasionally small, brilliant crystals of colorless chabazite, which are implanted on quartz.

At the Little Rapids mine, not far from the last, where well-defined bands or layers of apatite, often eight or ten feet wide, have been followed for considerable distances along the strike, and in one place to about 200 feet in depth, these are, nevertheless, seen to be subordinate to one great vein, similar in composition to those just described, and including bands of granular quartz. In some portions of this lode the alternations of granular pyroxenite, quartzite and a quartzo-feldspathic rock with little lenticular masses of apatite are repeated two or three times in a breadth of twelve inches.

The whole of the observations thus set forth serve to show the existence, in the midst of a more ancient gneissic series, of great deposits, stratiform in character, complex and varied in composition, and though distinct therefrom, lithologically somewhat similar to the enclosing gneiss. Their relations to the latter, however, as shown by the outlines at the surfaces of contact by the included masses of the wall-rock, the alternations and alternate deposition of mineral species and the occasional unfilled cavities lined with crystals, forbid us to entertain the notion that they have been filled by igneous injection, as conceived by Plutonists, and lead to the conclusion that they have been gradually deposited from aqueous solutions.

As one of the most interesting results of the extensive and costly mining operations carried out during the past few years, it has, we repeat, been demonstrated that the apatite really does traverse the entire stratum in which it is found, and that, if it is extremely pockety and deceptive in its occurrence, it nevertheless is perfectly persistent. It has also been proved that, to put it broadly, the same geological characteristics prevail throughout the belts.

It hence follows that all the deposits may be mined by the same method, and that, since we are called upon to deal with invariably mixed-up lodes, the quantity of apatite produced will be in direct proportion to the amount of rock removed.

After duly and seriously considering the problem from every standpoint, we venture to say that, if the best working mines could be all grouped together, the total ratio of pure apatite to other material could be brought up to about seven per cent.

It is true that there would be certain times when "bonanza" pockets would permit of very large production, but it is equally true that when the ordinary veins commence to "pinch," as they often do, the average production would be very small, or sometimes even *nil* until other bonanzas appeared. The figure of seven per cent. is therefore a very reasonable one as basis for calculations, when applied to Canadian mining as a whole.

A properly equipped mine, under the direction of a careful and experienced miner, *judicious* in his use of explosives, should be allowed the following force of men, employed as set forth:

20 men at prospecting or preparatory work over various parts of the property at $1.10 per day each for 300 days	$6,600
50 miners and strikers in shafts or quarries with one steam drill at $1.20 per day each for 300 days	18,000
10 men at surface labor, unloading, dumping, etc., at $1 per day each for 300 days	3,000
10 men in engine or machine shop, blacksmith shop and carpenter's shop at $1.20 per day each for 300 days	3,600
5 men in cobbing house at $1 per day each for 300 days	1,500
20 boys in cobbing house at 75 cents per day each for 300 days	4,500
115 men and boys employed daily—cost for the year	$37,200

From practical experience in this class of work it is estimated that the miners and prospectors will produce 5 tons of rock matter from the lode or belt per day and per man, and it has been found that the other labor and the plant must be regarded as accessory to this production.

Seventy men at 5 tons per day for 300 days will therefore produce 105,000 *tons of material*, which, at 25 cents per ton, will cost $26,250 for steam, explosives, wear and tear of plant, tools and general stores.

The cost of the apatite per ton at the mines, ready for shipment, will therefore be approximately as under:

Total yearly cost of labor	$37,200
Total cost of stores, etc.	26,250
Total expenditure at mine	$63,450

CANADIAN APATITE-MINING.

Boys cobbing and selecting the ore,

Total production of rock, 105,000 tons.

Seven per cent. of this quantity = 7,350 tons phosphate of all grades, from seventy to eighty-five per cent.

$$\$63,450 \div 7,350 \text{ tons} = \$8.60 \text{ per ton.}$$

These figures are suggested, we repeat, as those of the average mining cost, and it is hardly necessary to add that while some of the mines now working may be doing better, others are certainly not doing so well as this. In any event we must add to the figures the salaries of various officers and the interest on the capital invested in the purchase of the mine. If these items be grouped together under one head, we shall probably be within the mark if we charge them at the very moderate sum of $1.40 per ton on the amount of ore produced. This would therefore place the average net cost per ton, at the mines, at $10 for the qualities named. Again, it must be remembered that we are estimating the averages over the entire year. It would be obviously unfair to object to them that, when the mines are in "bonanza," the phosphate does not cost more than one-half the estimated amount, just as it would be unreasonable to claim, during a long period of "dead" work, that it costs twice or three times as much. When studying this question of cost, we must bear in mind that, owing to the mixed-up nature of the vein matter, nearly all the output has hitherto been put through the expensive process of hand-cobbing, as show in our illustration, in order to arrive at an average standard quality of from seventy-five to eighty-five per cent. of phosphate of lime. The impossibility of obtaining fairly remunerative prices for lower grades in Europe, which is the market for the entire Canadian output, has necessitated this cobbing and induced a state of affairs probably unprecedented in the history of any mining operations. We refer to the fact that the whole of the apatite mining companies have shipped no more than about one-third of their total production; the balance has been lost in the cobbing, and has been consigned to the dumps with the refuse, where it now remains as useless material!

That few, if any, of the enterprises have paid any dividends on their capital is not a matter for surprise under such circumstances as these, nor is any argument necessary to show how immeasurably their position would be ameliorated if a market were created for lower grade ores. The cost of transportation now renders these unfit for the market of Europe, but they are just the very class of

material required for the manufacture of fertilizers for home consumption, and it would be wiser policy to dispense with all the expensive processes of hand selection and cobbing at the majority of the mines, and to rest content with such an assortment at the quarry side as would insure an average grade of sixty per cent. The proportion of this quality to the total vein matter removed would be about double that of the pure apatite; in other words, instead of seven, the output could be placed at fifteen per cent., and the cost of cobbing would be saved.

The costliness of handling at the mine, however, is not the only impediment to the greater development of the apatite industry in Canada; another, and very serious obstacle, is the comparative inaccessibility of the deposits. One or two of the most important companies have gone to the expense of constructing shutes, or inclined railroads, for the carriage of their product to the river's banks, but by far the greater portion of the output has been rolled in wagons or sleighs over very indifferent roads generally leading to a rough storehouse, provided with a weighing shed and a Howe's scale. At this point different compartments or bins receive the phosphate according to its grade or quality, and a series of tramways connect the stored heaps with inclined shutes, whence the material is loaded directly into scows or barges on the river.

The actual cost of transport from the chief mining centres in the Quebec district to the wharf-side at Montreal has been the object of special inquiry, and the following figures have been obtained from official sources:

COST OF TRANSPORTING APATITE FROM THE CHIEF MINING CENTRES IN OTTAWA COUNTY TO THE WHARF AT MONTREAL.

Loading at mines, carting to and unloading at Riverside Store	$1 50
Loading into scows	05
Towing to Buckingham Village	18
Unloading scows and loading on cars of C. P. R. R.	12
Railway freight to Montreal	1 25
Wharfage, insurance and incidentals at Montreal	50
Total cost of transport from the mines per ton	$3 60

It would hence appear that the average cost of Canadian apatite delivered free on board vessels at Montreal outward bound for European ports must be placed at about $14 per ton, and

against this it will be of interest to study the selling prices which prevailed for the material during 1890.

TABLE SHOWING THE SELLING PRICES OF CANADIAN APATITE F. O. B. MONTREAL DURING 1890.

For phosphate	guaranteed	to	contain	85	per cent.,	$25	00	per ton.
"	"	"	"	80	"	22	50	"
"	"	"	"	75	"	18	00	"
"	"	"	"	70	"	14	50	"
"	"	"	"	65	"	11	25	"

If we could assume that the two highest of the above qualities formed the bulk of the material exported, it is evident that Canadian phosphate-mining would have to be placed in the front rank of profitable enterprises. Whether the bulk is thus composed, however, is a very perplexing question in the face of the following official figures showing the total quantities and values of ore yearly exported since the opening of the mines in 1877:

TABLE SHOWING THE YEARLY EXPORTS AND VALUES OF CANADIAN PHOSPHATES.

YEAR.	QUANTITY, TONS	VALUE, DOLLARS	YEAR.	QUANTITY, TONS	VALUE, DOLLARS
1877.....	2,823	47,084	1885.....	28,969	496,293
1878.....	10,743	208,109	1886.....	20,440	343.007
1879.....	8,446	122,035	1887.....	23,152	433,217
1880.....	13,060	190,086	1888.....	18,776	298,609
1881.....	11,968	218,456	1889.....	29,987	394,768
1882.....	17,153	338,357	1890.....	22,000	330,000
1883.....	19,716	427,668	1891.....	25,000	400,000
1884.....	21,709	424,240	1892.....	8,000	120,000

From the values thus recorded we gather that in the year 1885 about 29,000 tons were sold at the average of $17 per ton in Montreal, whereas in 1892 the output fell to 8,000 tons and the price to an average of $15 per ton at the same place. This would indicate that the average quality of the entire yield was seventy to seventy-five per cent. of tricalcic or bone phosphate, and in such a case the net profit on the entire exploitation could not have been very large.

Nothing could possibly be more confirmatory of our views of this mining field, therefore, than the official returns relating to it, and we cannot refrain from again insisting, and with additional emphasis, upon the necessity for an immediate and radical change of policy.

The custom of throwing the entire cost of production upon the high grades is unfair and should be discontinued. In its stead a rule should be established of setting aside for foreign shipment only such portions of the pure apatite as may be obtained directly from the lode without hand-cobbing at the surface. There would be no difficulty in disposing of these choice lots in Europe at very fair prices, and there is no doubt that with proper care and skill in the management they could be brought up to one-fourth of the total output. The balance of the material mined would certainly average more than sixty per cent., would probably go up to sixty-five, and would of course, as we have already explained, bear a far larger proportionate relation to the total rock removed than it does now. Since there is no lack of grinding facilities at Buckingham Village, quite close at hand, and since there are several abundant deposits of pyrites—the material required for sulphuric acid manufacture—in the immediate vicinity, it is self-evident that this low-grade material could be readily and cheaply transformed into an excellent superphosphate, containing at least fourteen per cent. of soluble or available phosphoric acid.

There would be no difficulty whatever in establishing a sale for such an article at a very fair rate of profit, and the demand simultaneously created for sulphuric acid by the adoption of this method would stimulate the development of the chemical industry in various branches, and new channels would thus be opened up for the safe and profitable investment of capital and the constant and remunerative employment of labor.

CHAPTER IV.

THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA.

THE amorphous and nodular deposits of phosphate of lime thus far discovered in the United States have been found in that portion of the rocks of the fourth geological period or "*Cenozoic*" time known as the *Tertiary Formation*, or "age of mammals," which immediately preceded the *Quaternary Formation*, or "age of man."

It is probable that the earth's surface really began to assume its present geographical aspect in this tertiary age, and a great part of its *fauna* and *flora* either closely resembled or was identical with a large number of our existing familiar species. Chief among its characteristics was a marked and continuous subsidence of the seas and an accompanying increased elevation of the land. The seas underwent evaporation; lagoons were formed; marshes were dried up; lakes were drained, and mountain chains arose and towered above deep valleys. The climatic conditions were next revolutionized, for the even temperature communicated by the earth's interior heat to an unbroken surface could no longer prevail. A redistribution of *fauna* and *flora* hence necessarily ensued, and numberless species were naturally exterminated before perfect acclimation could be accomplished. The fossilized remains of these extinct species, including incredibly gigantic reptiles and sea monsters, continue to afford a most interesting field for the study of paleontology, and have enabled us to recognize the pachydermatous *anoplotherium* as the oldest typical mammal, and to trace the succeeding true ruminant and carnivora and the endless swarms of shell-fish and bivalves right down to the present time.

The subdivisions of the tertiary age embrace three eras, which are respectively known to geologists as follows:

The Eocene Era, or age of nearly extinct species.

The Miocene Era, or age of which the species are more than half extinct.

The Pliocene Era, or age of which more than half the species are still living.

The rocks of the tertiary have been classified according to

certa n characteristic differences in their essential features arising from the fact that one portion of them was deposited by fresh and another by salt water. The oldest of them comprise gradually ascending beds of sands, clays, compact sandstones, loose shell-beds and calcareous sandstones, and they gradually develop into marls, clays, chalk, solid limestones and greensands. No other age was subjected at various intervals to more severe eruptive action, and its close was marked by immense disturbances, of which most of our active volcanoes remain as monuments for our wondering contemplation.

The portion of the tertiary strata in which our workable phosphate deposits are found may be broadly said to hug the coast of the Atlantic Ocean and the Gulf of Mexico from New Jersey to Texas, and to embrace within its area the most extensive marl-beds in the world.

Deposits of more or less commercial value and importance have been located and worked in Virginia, North and South Carolina, Alabama, Georgia and Florida, and there is no reason why they should not be found in large quantities in States where they are not at present known, or where they have only hitherto appeared to be of very low grade.

If no further discoveries should take place in our time, however, the vast beds of South Carolina and Florida are capable of yielding more than sufficient to supply the entire needs of the world far into the future, and as they are the only present sources likely to be extensively exploited in this country, we may dismiss all others without further comment.

In his work on "The Phosphate Rocks of South Carolina," Professor Francis S. Holmes tells us, in reference to their discovery, that in November, 1837, in an old rice field about a mile from the west bank of the Ashley River, in St. Andrew's Parish, he found a number of rolled or water-worn nodules of a rocky material filled with the impressions of marine shells. These nodules or rocks were scattered over the surface of the land, and in some places had been gathered into heaps so that they could not materially interfere with the cultivation of the field. As these rocks contained little carbonate of lime (the material of all others then most eagerly sought after), they were thrown aside and considered useless as a fertilizing substance. In December, 1843, in another old field he attempted to bore with an augur below the surface to ascertain the nature of the earth beneath, with the hope of finding marl. On

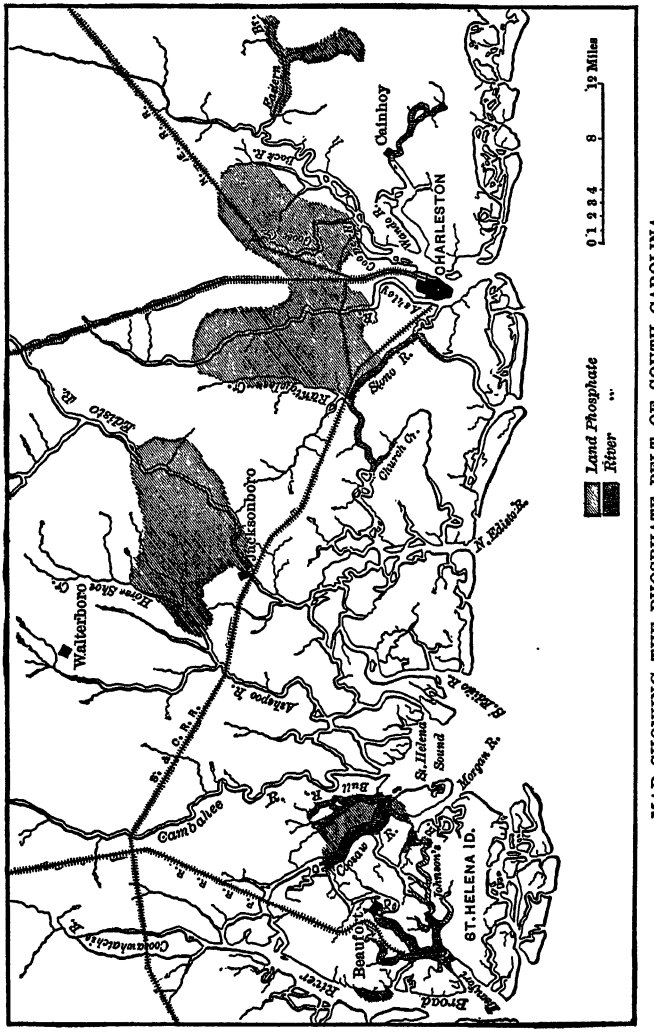
removing the soil above the rocks they were seen in a regular stratum about one foot thick imbedded in clay, and seemed to be identically the same as those found scattered on the surface of adjoining land, all of them bearing impressions of shells and having similar cavities and holes filled with clay. It was on the 23d or 24th of February, 1844, while engaged in the removal of the upper beds covering the marl, that the laborers discovered several stone arrow-heads and one stone hatchet. Not long after finding these relics of human workmanship, and while engaged in his usual visits to the Ashley marl-bed, Prof. Holmes found a bone projecting from the bluff immediately in contact with the surface of the stony stratum (the phosphate rocks); he pulled it out and beheld a human bone! Without hesitation he condemned it as an "accidental occupant" of quarters to which it had no right, geologically, and so threw it into the river. A year after, a lower jaw-bone with teeth was taken from the same bed. Subsequent events and discoveries show conclusively that the first-described bone was in "place," and that the beds of the post-Pliocene, not only on the Ashley River, but in France, Switzerland and other European countries, contain bones associated with the remains of extinct animals and relics of human workmanship.

The necessary lime or calcareous earth for manufacturing saltpetre on the west bank of the Ashley River during the Confederate war was obtained by sinking pits into the Eocene marl-bed.

Upon the removal of a few feet of the upper layers the workmen discovered in one pit a number of oddly-shaped nodules, resembling somewhat the marl-stones (phosphate rock) found in the stratum above the marl, but more cylindrical in form and not perforated, and having their exterior polished, as though each individual specimen had received a coat of varnish; they appeared to have been deposited in a large corner or pocket in the marl-bed. Upon submitting these samples to analyses their true value was revealed and South Carolina thereafter became a centre of attraction.

It was not until about 1867, however, that a mining company could be organized to test the practicability of working the phosphate on a commercial scale, but this company was no sooner started than it became a success, and the industry has since then progressed with such leaps and bounds that it has raised the status of South Carolina to that of the most productive phosphate field yet known to industry.

The geological formation of what is commonly called its phosphate "belt" is made up of quaternary sands and clays. These overlie the beds of Eocene marls, upon whose surface and inter-



MAP SHOWING THE PHOSPHATE BELT OF SOUTH CAROLINA.

mixed with which is found the phosphate deposit. The presumed total area covered by this characteristic formation, as shown by the map, is 70 miles in length and 30 miles in width, extending

from the mouth of Broad River, near Port Royal, in the southeast, to the head waters of the Wando River in the northeast. Its major axis is parallel to the coast, and its greatest width is in the neighborhood of Charleston.

Whether the deposit is continuous or not over the whole of this zone, it certainly varies considerably in depth and thickness. In many places we have seen it 3 feet thick and cropping out at the surface, whereas in others it has dwindled down to a few inches, or was found at depths varying from 3 to 20 feet. These two conditions, thickness of deposits and depth of strata, taken together with the richness of material in phosphoric acid, are of course the chief points for consideration in the economic working of the Charleston phosphate beds on an industrial scale.

The most approved and generally adopted method of ascertaining the importance and value of the deposits is that of boring and pit-sinking.

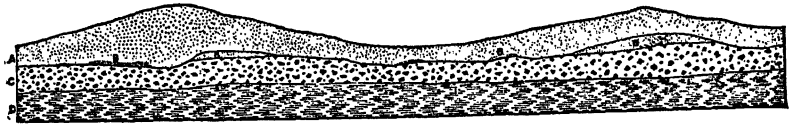
A careful topographical survey is first made of the country, and when this has been done there commences a systematic series of bore-holes from any point that may be arranged, by means of a long steel borer or rod, specially designed for the purpose. The boring rod is worked down through the upper strata until it is arrested by the solid bed of phosphate. Directly the slightest resistance is offered to its passage it is drawn up, and the distance it has traversed is measured with a foot-rule. The measurement having been noted, the rod is again let down, is forced through the resisting strata, and is then again withdrawn and measured. The difference between the first and second measurements is taken as representing the thickness of the phosphate bed. These bore-holes are practised at distances of 100 feet apart over the total surface to be examined. The results obtained with the rod are verified and confirmed by a series of exploratory pits—10 feet long by 5 feet wide —which are dug over the course of the bore-holes at intervals of 500 feet. The bore-holes are driven to a maximum depth of 15 feet, and no pits are at present sunk on those portions of the land where at that distance no phosphate has been encountered. Immediately after removing the overlying strata the phosphate is carefully taken out, its depth and thickness measured, and an average sample of the rock and nodules secured and laid aside for analysis.

The practically invariable nature of the superincumbent material throughout the entire belt, as shown by the digging of a

large number of pits under our direction, is represented in the following table, the figures being averages compiled from our field note-book:

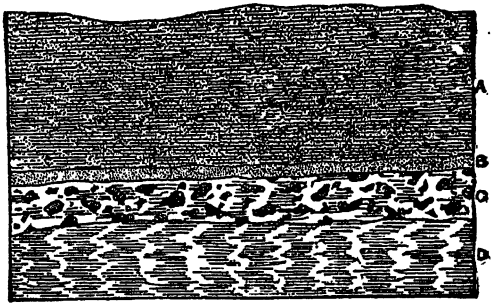
	CAINHOY.	JACKSONBORO.	EDISTO.	ASHLEY.
	Feet.	Feet.	Feet.	Feet.
Soil very black and acid	1½	1½	1	2
Mixture of sand and blue clay	2	3½	4	1½
Silicious clay	2½	2½	3½	4
Potters' clay mixed with shells	2	1½	3½	1¼
Sandy, hard conglomerate	traces	½	¾	2½
Phosphate rock or nodules mixed with blue clay	1½	1¼	1½	1¼
Depth of overlying beds	8	9½	12¾	11¼

This is still further illustrated and will be probably more clearly conveyed by the accompanying sketches of typical sections, prepared by R. A. F. Penrose, Esq., and borrowed from Bulletin No. 46 of the United States Geological Survey.



Section ENE. and WSW. through Pinckney's phosphate field, South Carolina. A, sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 60 feet.

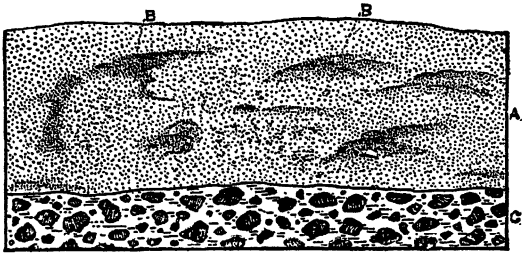
So far as we have been able to discover, no systematic investigation has been made of those lands which contain the phosphate



Average section in Pinckney's phosphate mine, Berkeley County, South Carolina. A, clay sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 6 feet.

deposit at a greater maximum depth than 15 feet, it having been hitherto considered impracticable, under the conditions of abun-

dant surface supply and consequent low mining cost, to conduct a profitable exploitation at any greater depth. A far wider area of lands than those actually classed as mining properties may therefore contain the very same deposit of phosphate, lying under a con-



Section in one of Fishburne's pits, South Carolina. A, sand; B, ferruginous sand; C, phosphate nodules in clay matrix. Scale: 1 inch = 7 feet.

siderably greater accumulation of the quaternary strata, and this is the view we are personally disposed to adopt as representing the facts. Whether or not, however, in face of the recent Florida phosphate discovery, any economical means will ever be devised in our time to exploit them at a profit, should they really exist, is a question as to which we are in very serious doubt.

The phosphate deposits in South Carolina are of two kinds, the "River" and the "Land," but the material found in the river bottoms of the "belt" is of practically the same chemical description as that of the land, having, in fact, been merely washed into them from its original beds. It has been worked extensively and has proved to be of great commercial value, since it is obtained by the simple and inexpensive process of dredging, and is thus raised and washed free from all adhering impurities by one and the same operation.

The dredging scoops are made extremely massive in order that they may break through the nodular stratum, and the boats are held in position at the four corners by "spuds" or strong square poles with iron points, which are dropped into the water before dredging is begun, and afford a strong support for the boat by going through the nodule stratum and down into the river-bed below. The nodules are thrown from the scoop into the washer, which is on a lighter alongside the dredging boat. The washer, in some cases, is the same as those used by the land-mining companies, to be presently described, but often it consists of a truncated cone, with perforated sides, revolving on a horizontal axis. It is sup-

plied on the inside with steel spirals, arranged around the side like the grooves in a rifle, and heavy streams of water flow into its two ends. The nodules are dumped by the dredge into the small end of the cone and come out at the large end. They are then removed by a derrick to another lighter and towed to shore.

The dredging machine is not the only means employed for raising the river phosphate, some companies having adopted a contrivance consisting of six large claws, which open when they descend, and close, forming a kind of bucket, when they rise. It is said that some of these machines can dredge in 50 to 60 feet of water, while the ordinary dredging boat cannot raise the phosphate in over 20 feet.

Both the rock and nodules from these river and land deposits occur in very irregular masses or blocks of extremely hard conglomerate of variegated colors, weighing from less than half an ounce to more than a ton. The mean specific gravity of the material is 2.40, and it is bored in all directions by very small holes. These holes are the work of innumerable crustaceæ, and are now filled with sands and clays of the overlying strata. Sometimes the rock is quite smooth or even glazed, as if worn by water; at others it is rough and jagged.

Interspersed between the nodules and lumps of conglomerate are the fossilized remains of various species of fish and some animals, chiefly belonging to the Eocene, Pliocene or post-Pliocene ages.

Very careful analyses of a large number of the samples of land rocks taken from the pits and made in our laboratory gave, after being well dried at 212° F., the following average:

Moisture, water of combination and organic matter lost on ignition	8.00
Phosphate of lime	59.63
Carbonate of lime	8.68
Iron and alumina (calculated as oxides)	6.60
Carbonate of magnesia	0.73
*Sulphuric acid and fluoride of lime	4.80
Sand, siliceous matters and undetermined	11.56
Total	100.00

While it is shown by these figures that the grade of this phosphate is not extremely high, it has been proved by experience all over the world to be admirably adapted for the purpose of manufacturing commercial fertilizers, and it will doubtless long con-

* The sulphuric acid represents the sulphur combined with iron as pyrites.

tinue for this reason to maintain a leading position as a raw material.

Before the land rock can be made available for industrial purposes, it is made to pass through three distinct and successive operations.

1. Mining or excavating.
2. Washing it free from sand and other impurities.
3. Kilning, to free it from moisture.

Taking these in their order, it is customary to establish a main trunk railroad, starting at the river front or on the bank of some convenient stream, and passing right through the centre of the property to be exploited.

Alternate laterals can be run off at right angles from any portion of this main line, at distances of, say, 500 feet, in conformity with the nature of the ground. Between and parallel to these laterals a ditch or drain is dug to a depth extending 4 to 5 feet below the phosphate strata. From this main drain the excavators start their lines at right angles to the laterals, commencing at one end of the field and digging trenches 15 feet wide and 500 feet long, the work being so arranged that the men are stationed at intervals of 6 feet. Every man is supposed to dig out, daily, a "pit" 6 feet long, 15 feet wide, and down to the phosphate rock. The overlying material is thrown out to the left-hand side of the trench. The phosphate itself is thrown out to the right and taken in wheelbarrows to the railroad cars which pass at either end of the trench. The water drains from the trenches into the underlying ditch, and is thence pumped out by means of a steam-pump worked by a locomotive engine. The pump and the engine are secured to connected railway platforms, and run along the railroad track from one ditch to another as occasion requires.

The cars, loaded with the crude phosphatic material dug out of the pits, are run down to the washing apparatus, constructed at an elevation of some 30 feet from the ground, and generally consisting of a series of semi-circular troughs 20 to 30 feet long, set in an iron framework at an incline of some 20 inches rise in their length. Through every trough passes an octagonal iron-cased shaft provided with blades so arranged and distributed as to form a screw with a twist of one foot in six, which forces the washed material upwards and projects the fragments against each other. The phosphate-laden cars are hauled up an incline and their contents dumped into the bottom trough, where the phosphate en-

counters one or more heavy streams of water, pumped up by a steam-pump. This water does not run off at the bottom, but overflows at the higher end near where it enters. When sufficiently washed, the material is pushed out upon a half-inch-mesh screen; the small *débris* being received on oscillating wire tables below.

The phosphate is now ready for kilning or drying, and of all the methods hitherto adopted for this important process, that of simple roasting in an ordinary kiln, such as is generally used in the manufacture of bricks, is said to have been found at once the most rapid, effective and economical.

The rock is built on layers of pine wood, and owing to its containing a considerable quantity of organic matter, it readily lends itself to combustion and requires but a short time to become quite red-hot.

The kilns are made sufficiently large and are so arranged as to allow free passage to a train of cars, which, running on the main line of railroad, can be loaded in the kiln, run down to the landing place and discharged directly into the barges or boats on the river.

Since the beginning of operations in 1868, the yearly quantities of phosphate taken from the South Carolina rivers and mines have been:

Year.	*Land Rock.*	*River Rock.*	*Total Tons.*
1868–70	18,000	1,989	19,989
1871	33,000	17,655	50,655
1872	38,000	22,502	60,502
1873	45,000	45,777	90,777
1874	43,000	57,716	100,716
1875	48,000	67,969	115,969
1876	54,000	81,912	135,912
1877	39,000	126,569	165,569
1878	113,000	97,700	210,700
1879	102,000	98,586	200,586
1880	125,000	65,162	190,162
1881	141,000	124,541	265,541
1882	190,000	140,772	330,772
1883	226,000	129,318	355,318
1884	258,000	151,243	409,243
1885	224,000	171,671	395,671
1886	294,000	191,194	485,194
1887	230,000	202,757	432,757
1888	260,000	190,274	450,274
1889	250,000	212,101	462,101
1890	300,000	237,149	537,149
1891	270,000	130,000	400,000
1892	225,000	125,000	350,000
Totals,	3,526,000	2,689,557	6,215,557

And the number and the importance of the companies actually engaged in mining are shown in the following table:

LAND PHOSPHATE COMPANIES.

Name.	*Address.*	*Capital.*
Williman Island Co	P. O., Beaufort; works, Bull River.	$200,000
Bolton Mines (K. S. Tupper)	P. O., Charleston; works, Stono River	50,000
Charleston Mining & Manufacturing Co	P. O., Charleston; works, Ashley River	1,000,000
Campbell & Hertz	P. O., Rantowles; works, Rantowles Creek	50,000
Bulow Mines (Wm. M. Bradley)	P. O., Charleston; works, Rantowles Creek	250,000
Mt. Holley Mining & Manufacturing Co	P. O., Charleston; works, Mt. Holley, N. E. R. R	50,000
C. H. Drayton	P O., Charleston; works, Ashley River	50,000
William Gregg	P. O., Summerville; works, Ashley River	50,000
F. C. Fishburne	P. O., Jacksonboro; works, Pon Pon River	50,000
Meadville Mines (E. Meade)	P. O., Charleston; works, Cooper River	300,000
Magnolia Mines (C. C. Pinckney)	P. O., Charleston; works, Ashley River	100,000
Rose Mines (A. B. Rose)	P. O., Charleston; works, Ashley River	100,000
Wayne & Von Kolnitz	P. O., Charleston; works, Ashley River	50,000
St. Andrews Mining Co	P. O., Charleston; works, Stono River	200,000
Hannahan Mines	P. O., Charleston; works, Cooper River	50,000
Horse Shoe Mining Co. (Wm. Gregg)	P. O., Charleston; works, Ashepoo River	50,000
Wando Phosphate Co	P. O., Charleston; works, Ashley River	200,000
T. D. Dotterrer	P. O., Charleston; works, Ashley River	25,000
Archdale Mines (Hertz & Warren)	P. O., Charleston; works, Ashley River	20,000
Pacific Guano Co	P. O., Charleston; works, Bull River	100,000
Eureka Mining Co	P. O., Charleston; works, Jacksonboro, C. & S. R. R	40,000

RIVER PHOSPHATE COMPANIES.

Name.	*Address.*	*Capital.*
Beaufort Phosphate Co..	P. O., Beaufort; works, Beaufort River.	$100,000
Coosaw Mining Co.....	P. O., Coosaw; works, Coosaw and Bull rivers.....	600,000
Carolina Mining Co.....	P. O., Beaufort; works, Beaufort River.	250,000
Farmers' Mining Co.....	P. O., Beaufort; works, Coosaw River..	125,000
Oak Point Mines Co.....	P. O., Beaufort; works, Wimbe Creek...	150,000
Sea Island Chemical Co.	P. O., Beaufort; works, Beaufort River.	250,000

Of the river companies, the Coosaw, which for many years has been one of the chief operators, was in 1891 compelled to suspend its production on account of a serious controversy with the State, and in this connection it will be interesting to refer to a message which was sent to the Legislature by the Governor of South Carolina on the 1st of March, 1891, in which he makes the following statement:

"In 1870 the Legislature granted privileges to a corporation known as the River and Marine Company to mine rock in the navigable waters of the State for twenty-one years. The State received nothing for this valuable franchise. The Coosaw Mining Company obtained from the original grantors exclusive right to mine in Coosaw River, and with a paid-up capital of $275,000 commenced operations. In 1876 the General Assembly passed an act confirming the exclusive right of the Coosaw Company to mine in that river for the term of twenty-one years at a fixed royalty of $1 per ton, and this lease has now expired. The act of 1876 was drawn by the attorney of the Coosaw Company, and so adroitly worded as to give color to the claim that the grant of that river was perpetual 'so long as that company shall make true returns,' etc., and under this the company claims that its tenure is not a lease expiring in 1891, but a contract running for all time. This claim is preposterous, and this General Assembly must not hesitate to move forward and act promptly and decisively.

"The Coosaw River, to which this company lays claim, is, perhaps, the best phosphate field in the world, and the lease under which it has been mined for twenty-one years has made every stockholder wealthy. Their plant, which has been obtained from the surplus profits, is valued at $750,000 or over; and in the mean time, by fabulous dividends, the original capital of $275,000 has been returned to the stockholders, as I am informed, over and over again. When you are told that the output of this company this year has been 107,000 tons, worth $7 per ton f. o. b., and that the cost of

mining this rock, including royalty, cannot exceed $4.25 per ton, and is believed by many to be much less, you will see that the margin of profit exceeds one hundred per cent. on the original investment. The total royalty secured by the State from its phosphate has been over $2,000,000, and of this amount over half has been paid by the Coosaw Company.

"The expiration of the Coosaw lease in March next makes it possible to double the income of the State from the phosphate royalty without injuring the industry or interfering unduly with any vested right. We therefore demand a survey of the phosphate territory and the sale of its lease at auction to the highest bidder, after a minimum royalty has been fixed by the board of control upon each district surveyed. Anything less than a thorough and reliable survey would be a waste of time and money, and this will take a good deal of both. But it will repay its cost, and until we have the data which alone can be thus obtained, we cannot legislate intelligently or derive the benefits from this valuable property that we ought. This year the royalty has been $237,000, and all of it except $3,000 was paid by six large mining corporations, whose field of operations is confined to a territory within twenty miles of Beaufort. You will be told by some that this indicates an exhaustion of the deposits; but I am sure it only means that good rock is more plentiful or more cheaply mined there than elsewhere. A survey alone can demonstrate the truth or falsity of this belief, which is based upon the assurance of experts who themselves have mined in other waters of the State, and as the reliance of capitalists upon an estimate of the value of any given deposit of phosphates will depend largely upon the character of the man making the survey, I have thought it best to obtain the help of the United States Government, if possible, and ask the detail of an officer of the Navy or Coast Survey to do the work. I think an appropriation of $10,000 will be sufficient to start with, and by the time the General Assembly meets a year hence, it will have something definite to go upon and can continue the work or not as it may deem best. In the mean time, by means of this survey and the opportunity for further investigation, to which all my spare time shall be devoted, a clearer understanding as to the best system of management of this important industry can be obtained and the General Assembly can then act intelligently.

"When the Coosaw lease expires, March 1 next, let us open that river to all miners who choose to enter it; allow the board of

control to parcel out the territory among them so as to prevent conflict; raise the royalty to $2 per ton and place one or more inspectors on the ground to supervise the work and weigh the rock when shipped. All the river rock mined in South Carolina is exported to Europe, and last year the demand was so great as to necessitate the exportation of 40,000 tons of land rock, while the price has steadily increased since 1887."

This was a strong message, and how far Governor Tillman is justified in assuming the river deposits to be either "practically inexhaustible" or to have been very little affected by the enormous drain to which they have been subjected during the past twenty years, is a question of extreme delicacy. To what extent it was politic or wise on the part of the State to increase the first cost of a raw material which is now meeting with fierce competition from a most formidable and naturally favored rival is also a matter for very serious consideration. In any event, the fact remains that the Coosaw Company saw fit to disagree with the views of the Governor and joined issue with the State on the question of right. When the State Phosphate Commission, therefore, took possession of the Coosaw River territory, on the 2d of March, 1891, and made preparations to lease it to all who applied for a license, the company filed a protest, and on March 6th was granted a temporary injunction by Judge Simonton, of the United States Court, whereby the State Phosphate Commission was enjoined from entering upon, or otherwise interfering with, that part of the Coosaw River which the company had previously occupied. As a first result of the litigation the Chief Justice of the Supreme Court decided as follows:

"The acts of 1870 and 1876 must be construed in *pari maturia.* Under the first act the State gave the grantees for twenty-one years the right to mine in its navigable streams. This grant was upon the condition that the grantees should pay annually $1 a ton on each ton dug and mined, and that they make a return of their operations annually, or oftener if required. This was not an exclusive right (Bradley *vs.* The Phosphate Company, 1 Hughes). It was upon condition; that is to say, it existed so long as the conditions were fulfilled and no longer. The act of 1876 proposed modification of this contract in four particulars.

"1. The time for making the returns was definitely fixed at the end of each month. This was an advantage to both parties.

"2. The royalty was made payable on each ton dug, mined and shipped, not on the rock mined. This was in favor of the grantees.

"3. The royalty was made payable quarterly, not annually, this provision to go into effect immediately and royalty for the two quarters of the current year to be paid at once. This was in favor of the State.

"4. The right to mine, therefore, if not exclusive, was made exclusive on account of the acceptance of the State's proposals.

"The original contract was unchanged in every other respect. The royalty remained the same, $1 per ton. The grant was wholly on condition, that is to say, existed so long as and no longer than the conditions were fulfilled. The duration of the grant during which these conditions were of force was unchanged—twenty-one years from 1870.

"This is a reasonable construction of a doubtful act by which the doubt is resolved in favor of the sovereign grantor; it is a familiar rule of construction that when a statute operates as a grant of public property to an individual, or the relinquishment of a public interest, and there is a doubt as to the meaning of its terms or its general purpose, that construction will be adopted which will support the claim of the government rather than that of the individual. Nothing can be enforced against the State."

This decision was confirmed on appeal, and the Coosaw River was at once thrown open to all comers at the old royalty. A largely increased production was followed by so serious a fall in prices that the State must now either reduce its royalty or see the industry come to a standstill.

It will have been noticed that in the course of his message the cost of producing one ton of river rock in marketable condition was placed by the Governor at $4.25 per ton, including the $1 royalty paid to the State, and that this is a fairly correct statement is borne out by the facts elicited in 1886 by a commission especially appointed by the Legislature to investigate the subject. The same figures apply with equal fairness to the cost of the land phosphate, as demonstrated by the testimony sworn to by various experts before the examining body and by our own practical investigation in the field. With a properly constructed plant, regular drainage and efficient and economical management, we find that the total cost of production of land phosphate in clean, dry, marketable condition may be thus stated:

Mining at a maximum depth of 15 feet	$1.00
Draining the mine	25
Loading on cars and carrying to washer	60
Washing	30
Drying and handling in kiln	50
Shipping from kiln into vessels on river	25
Interest on capital invested in plant and repairs to same	15
Superintendence and management of mines	20
Towage to Charleston, say	25
Total per ton of 2,240 pounds	$3.50

The present selling price of dry phosphate containing a mean average of fifty-seven per cent. tribasic or "bone phosphate" of lime is about $4.50 per ton of 2,240 pounds on wharf at Charleston, and if we may judge of the total net profits accruing to the miners during the past twelve months by the results shown by some of the companies whose published accounts have been placed at our disposal, they cannot be estimated at more than 50 cents per ton.

Of the total phosphate mined in the State, more than one-third is actually used in fertilizer factories situated in and around Charleston and owned by the following companies:

Port Royal Fertilizer Co.	Port Royal, S. C.
Baldwin Fertilizer Co.	Port Royal, S. C.
Atlantic Phosphate Co	Charleston, S. C.
Ashley Phosphate Co.	Charleston, S. C.
Edisto Phosphate Co.	Charleston, S. C.
Wando Phosphate Co.	Charleston, S. C.
Berkeley Phosphate Co.	Charleston, S. C.
Etiwan Phosphate Co.	Charleston, S. C.
Ashepoo Phosphate Co.	Charleston, S. C.
Stono Phosphate Co.	Charleston, S. C.
Imperial Fertilizer Co.	Charleston, S. C.
Mead Phosphate Co.	Charleston, S. C.
Royal Fertilizer Co.	Charleston, S. C.
Chicora Fertilizer Co.	Charleston, S. C.
Wilcox & Gibbes Fertilizer Co.	Charleston, S. C.
Globe Phosphate Co.	Columbia, S. C.
Columbia Phosphate Co.	Columbia, S. C.
Greenville Fertilizer Co.	Greenville, S. C.

The combined total output of superphosphates by these companies for the average year is estimated at about 300,000 tons.

Assuming this quantity to require in round numbers 150,000 tons of raw phosphate, and further assuming the output of the latter to be an all round average of 450,000 tons, there remains an available surplus over local requirements of 300,000 tons of phosphate of lime. Of this quantity about one-half may go to Great Britain and Germany and the balance will go coastwise to Richmond, Baltimore, Philadelphia, and New York.

There can be no doubt that, as we have already remarked, South Carolina rock must be regarded as a raw material of the first class in the manufacture of soluble and available phosphates, and that, as such, it is and will continue to be everywhere held in the highest esteem. In Europe it is generally used in combination with Belgian cretaceous phosphates and very high-grade Canadian apatites, and in this way yields results that cannot be surpassed by any other material as an all-round staple, uniform and reliable article.

If we were asked to express an opinion in an off-hand way as to the probable extent and capacity of the yet untouched or unexploited deposits, we should hesitate to give any decided answer because of the lack of sufficient data or reliable figures. From information which we have been able to gather, however, from sources in which we have every reason to place the fullest confidence, the explored but still unexploited area covered by land and river deposits embraces an area of no less than thirty miles. Regarding this as a mere approximation to the possible truth, we might venture. in the same spirit of speculation, to place the yield of this area at the present average of 750 tons to the acre.

The conclusion drawn from these hypotheses would be that the State may be relied upon to still produce about 14,000,000 tons, and allowing for a continued average production and sale of, say, 50,000 tons per month, either for local consumption or export trade, it would appear as if the mines would all be exhausted in about twenty-eight years from the present time.

Whether the mining companies now in the field have or have not entertained this view of the matter, it is impossible to say, nor is it very material to the issue. The fact remains that the known available and readily accessible deposits are all appropriated, and that no falling off in the *domestic demand* for the product has yet been traceable to the influence of any other source of supply. As time rolls on, local manufacturing requirements cannot fail to increase in large proportions, and we regard it as even highly probable

that at no distant date this source of consumption will absorb all that can be produced, and thus while the profitable nature of the mining operations will be increased, there will be no balance available for other markets.

CHAPTER V.

THE PHOSPHATE DEPOSITS OF FLORIDA.

The existence of nodular amorphous phosphate deposits in Florida is not a matter of recent discovery, for they had been found in various directions many years ago, but were never believed to be of sufficient importance either in quantity or quality to merit the serious attention of capitalists. Like many other of our natural resources, therefore, they remained long dormant and unthought of.

The first tentative mining operations were commenced in the year 1888 by The Arcadia Phosphate Company on a very small scale in Peace River, and they met with such marked encouragement that many who had hitherto remained sceptically watching their efforts came into the same field, and the year 1889 saw the Peace River Phosphate Company and the De Soto Phosphate Company dredging the river with an expensive modern plant.

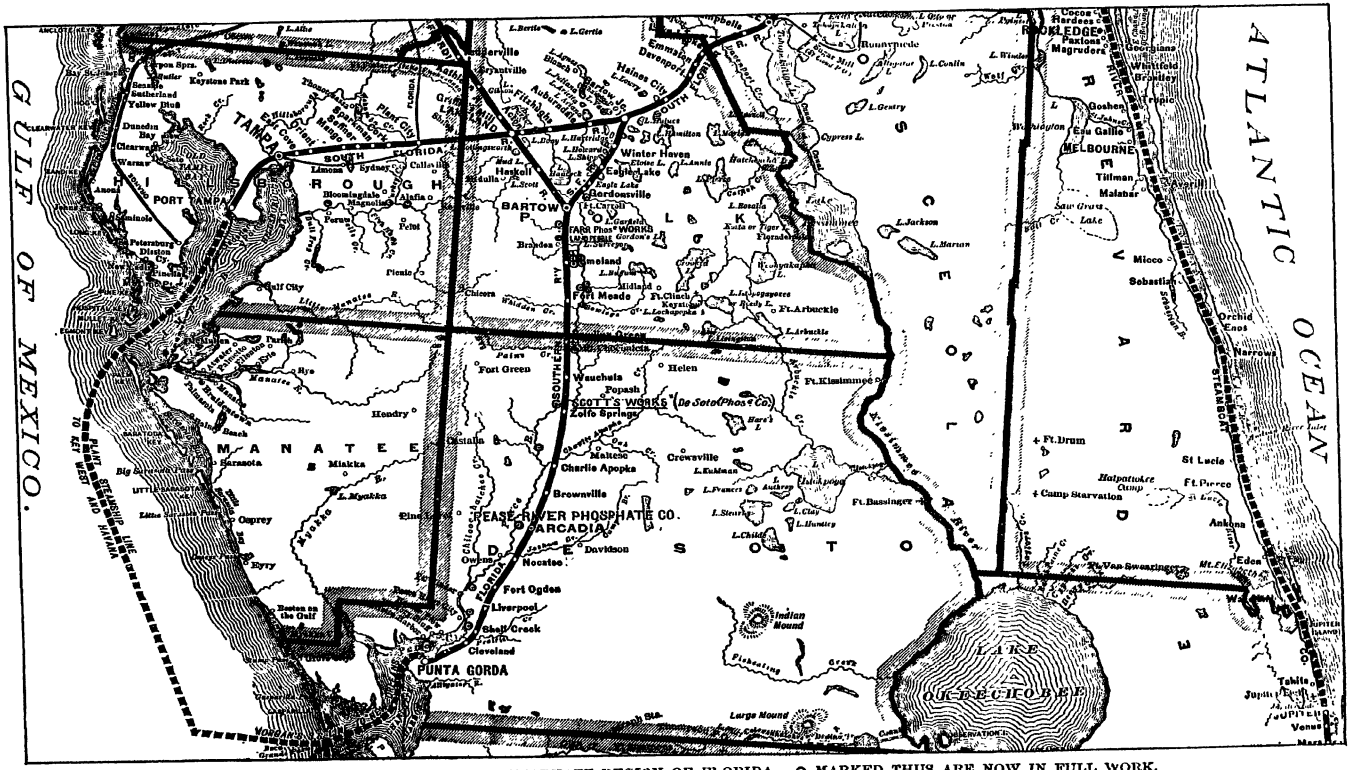
The unostentatious and cautious manner in which these corporations conducted their business for some time, prevented their movements and successes from being noised abroad, but when the attention of those in the immediate locality could no longer be diverted from the facts, universal interest was aroused and prospectors went to work in all parts of the State. Discovery now followed discovery in rapid succession, and each new field was claimed to be of more value and importance than its predecessor. The land-owners became excited; wealth "beyond the dreams of avarice" danced before their eyes and reposed under their feet. The local newspapers started a "boom" and all Florida was in the throes of a wildly exaggerated and feverishly speculative phosphate fever. Lands which heretofore were valued at from $1.50 to $3 per acre readily changed hands at $150 to $200 per acre, and many a "cracker homesteader" who went to bed a poor man woke up in the morning to find himself a capitalist.

Until the discovery of the phosphate beds it had always been customary, so far as we can remember, to speak and think of Florida as a combination of sand-banks and uninhabitable tropical swamps, and apart from the few adventurous "Yankees" who had

"gone in" for orange culture, no one seemed to manifest any interest in its destiny and nothing seemed more unnecessary than a prolonged visit from the officers of the Geological Survey. This of course rendered it extremely difficult for us to conduct our first examinations, and the more so, since the various properties we were requested to report upon compelled us to virtually traverse every county on the Gulf of Mexico from Tallahassee to Punta Gorda. We had no important data at our hand for reference, save perhaps the old notes of Le Conte and Agassiz, and the more recent paper of Professor E. A. Smith, of Alabama, and as these were comparatively of little value for our purposes, we were compelled to construct our own rough topographical and geological map as we went along.

The belt within which is confined the deposits of phosphates of the variety known as "hard rock" may be said to commence at the head of the Wacissa River, in Jefferson County, about four miles south and eighteen miles east of Tallahassee. Extending from this point southeast through Jefferson, Madison, and Taylor counties to the Steinhatchee River in Lafayette County, it continues to the north, and lies upon the east bank of the Suwanee River, in the neighborhood of Luraville; goes on southeast to Ichetucknee Springs, in Columbia County, and southward to Fort White, crossing the Santa Fé River into Alachua County, and on to Levy County. South and east through Levy County to Stafford's Pond, it wends its way through Marion County across the Withlacoochee River into the counties of Citrus and Hernando. Here it broadens out to the east, takes in the western border of Sumter County, and, veering again to the west, passes on to a point about five miles south of Dade City, in Pasco County, where it reaches its northern limit. Its total length thus appears to be somewhere in the neighborhood of 160 miles, and we estimate its average width at about twelve miles; its general trend being N.N.W. and S.S.E., conformably to the configuration of the Gulf coast.

The deposits pertaining to the variety known as "Pebble" cover a region which spreads out for some thirty miles east and west to the south of Lakeland, at right angles with the general trend of the deposits of hard rock. They are distributed along the water-courses of Polk and Hillsborough counties, until they are lost in the Alafia River, and they branch off southwards at this point with a narrowing tendency down the Peace River valley to Charlotte Harbor.


GULF OF MEXICO.
ATLANTIC OCEAN
TAMPA
PORT TAMPA
SOUTH FLORIDA
ROUGH
BARTOW
PEACE RIVER PHOSPHATE CO.
ARCADIA
DE SOTO
MANATEE
HARDEE
OKEECHOBEE
LAKE
PUNTA GORDA
MELBOURNE
ROCKLEDGE
Winter Haven
Bartow
Fort Meade
Fort Green
Wauchula
Zolfo Springs
Arcadia
Charlie Apopka
Brownsville
Davidson
Nocatee
Fort Ogden
Liverpool
Shell Creek
Cleveland
Punta Gorda
Sarasota
Mikka
Myakka
Osprey
Eyry
Manatee
Bradenton
Palmetto
Ellenton
Parrish
Terra Ceia
Pinellas
Dunedin Bay
Clearwater
Safety Harbor
Tarpon Springs
Anclote
Keystone Park
Sutherland
Yellow Bluff
Limona
Sydney
Bloomingdale
Magnolia
Lithia
Valrico
Brandon
Plant City
Sydney
Dover
Hillsborough
Alafia
Peace
Myakka
Manatee
Braden
Horse Creek
Peace Creek
Payne Creek
Charlie Creek
Joshua Creek
Big Slough
Little Slough
Big Sarasota Pass
Little Sarasota Pass
Gulf City
Pinole
Feist
Perry
Austin
Callahan
Haskell
Bartow
Auburndale
Lakeland
Winter Haven
Eagle Lake
Bartow
Fort Meade
Midland
Homeland
Peace River
Fort Green
Wauchula
Popash
Helen
Hondry
Ft. Ogden
Liverpool
Shell Creek
Cleveland
Punta Gorda
Boston on the Gulf
Gasparilla Island
Boca Grande
Pass
Charlotte Harbor
Placida
Rye
Manatee
Parrish
Ellenton
Palmetto
Bradenton

FLORIDA ROCK-PHOSPHATE MINING.

Removing overburden of sand by the "Gopher" machine, Dunnellon Mines, Marion Co.

The topography of Florida is the result of a combination of dynamic agencies with processes of sedimentation, erosion, and chemical solution, and in the opinion of G. H. Eldridge, Esq., of the United States Geological Survey, it is the direct southern extension of the coastal plain of the Atlantic and Gulf States. It is, therefore, a region in the evolution of which sedimentation has formed a prominent feature. The peninsular portion, on the contrary, seems to have had an independent origin, and is probably a modification of the emerged crest of an anticlinal fold that extends for many miles beneath the sea on either side.

The peninsula exhibits two distinct phases: the one, that of a comparatively high, undulating country; the other, that of flat lowlands. The former is limited to a broad median belt in the northern half of the peninsula; the latter, with slight modification, constitutes the entire southern half of the peninsula, and in the northern half forms along the coast a border to the more elevated central region. The drainage of the peninsula is essentially north and south, although all the streams have, along some portion of their length, an east and west course, which carries them from the interior towards the periphery of the State. The chief rivers of the peninsula are: on the east side, the St. Johns and the Kissimmee systems, now connected by canals, the latter draining into the Gulf through the Caloosahatchee River; in the central, more elevated regions, the Ocklawaha; on the west side the Santa Fé, Suwanee, Withlacoochee, and Peace rivers. The water-sheds of these streams are nowhere more than 250 or 300 feet above sea-level. Over much of the central area there is a vast detail of topography within slight vertical range which modifies the surface into a confused mass of hills, a feature largely due to the superficial deposits of sands, laid down just before the last emergence of the peninsula from the sea. In the lowland region the elevations between the rivers are hardly perceptible, except again for local modifications by sand-deposits; the streams are sunk with sharp banks to varying depths beneath the general surface; the topography is, in fact, that of an extended, monotonous, though often timbered prairie.

The formations involved in the phosphate belt are of several ages, and the topography varies accordingly. From the vicinity of Dade City, in Pasco County, northward nearly to the State line, the country is underlain by a broad belt of Eocene limestones, of considerable thickness and without stratification-planes.

Their soft materials have been subjected to erosion and solvent processes both at and beneath the surface. The rock is channelled by underground streams, the presence of which is determined by their effect seen in numerous sink-holes throughout the area of the formation. Depressions occupied by large bodies of water are at times emptied of their contents through these openings and channels, and it is probable that extended tracts of land have been converted into lakes by the general lowering of the surface through the removal of masses of the underlying limestone. This Eocene area of Florida is, therefore, undulating and irregular, an effect further heightened by the deposits of sands from the last submergence.

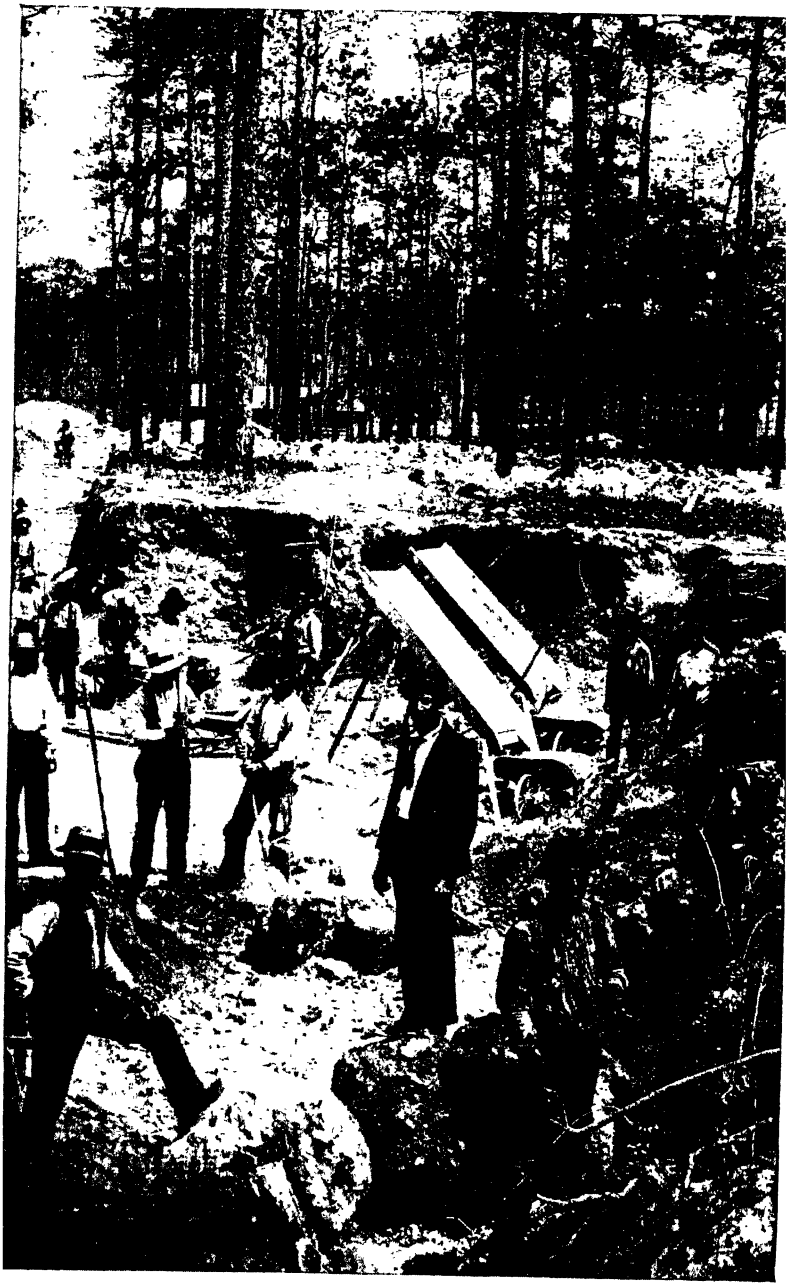
In western Florida, however, the upper formation is of Miocene age, and consists of thin-bedded, horizontal limestones. This causes the topography to be that of the "flat woods" and swampy lowlands, with natural bridges but with few sinks. In the hard-rock phosphate regions the general elevation is less than 75 feet above sea level.

In the angle of the South Florida and Florida Southern railroads, in the vicinity of Lakeland and Bartow, lies the water-shed of the region to the south and west. It reaches an altitude of 208 feet at Lakeland, but rapidly falls with the drainage to 117 feet at Bartow, 131 feet at Plant City, and elevations still lower as the coast is approached. The underlying beds of marls, clays, and pebble-phosphate give it a topographical aspect differing considerably from that of the hard-rock regions. With some exceptions its general appearance is that of the "flat woods" lowland country, modified into a gently undulating surface by the superficial deposits of sands. As the coast is approached, it graduates into the vast reaches of flat lowlands so characteristic of south Florida and the general coastal border of the State. The region of the Peace, Alafia, Manatee, and Caloosahatchee rivers, and of the great lakes which the last drains, is of the true lowland type, but is locally modified to an irregular surface by the superficial sands.

There are evidences throughout the phosphate region, and also in many other portions of Florida, of the great predominance of chemical solution over mechanical abrasion in the cutting of stream courses and the moulding of general topographical features. Nowhere in the United States are these forces to be observed in such prevalence at the present day, and nowhere are the

FLORIDA ROCK-PHOSPHATE MINING.

Open cut in Cove Bend Phosphate Company's mine, Inverness, Citrus Co.



FLORIDA ROCK-PHOSPHATE MINING.

Working in "boulder" material after removal of top soil.

evidences so abundant of their past action and their agency in the development of both topography and geology.

The phosphate regions of Florida are covered either with a heavy growth of pines, as in the sandy areas, or with deciduous growths, as in the region of sinks and in the peculiar areas known as hammock-lands, while in the swamp-lands the cypress, oak, gum, ash, magnolia, and bay are the chief timbers.

The topography of the country being thus established, we need not pause to consider the climatic conditions, which are sufficiently well known, but may at once pass on to a consideration of the most prominent geological aspects. The fact that so large a portion of the State is shown to be actually underlaid with tertiary limestones of the variety known as "Vicksburg" points to the Eocene age as the most probable date of its first emergence. This opinion is based on our own careful examination of many artesian wells at widely distant points, and is particularly sustained by the well at Lake Worth, which was completed in June, 1890, and of which the following detailed particulars have been published by N. H. Darton, Esq., of the United States Geological Survey:

0–400 feet.	Sand with thin layers of semi-vitrified sand at 50 and 60 feet.
400–800 "	Very fine-grained soft, greenish-gray quartz sand, containing occasional foraminifera and water-worn shell fragments.
800–850 "	No sample.
850–860 "	White sands with abundant foraminifera of four or five species.
860–904 "	No sample.
905–915 "	Gray sands containing sharks' teeth, small water-worn shell and bone fragments, sea-urchin spines and lithified sand fragments.
915–1000 "	No sample.
1000–1212 "	Samples at frequent intervals. Vicksburg limestone, containing orbitoides in abundance throughout, together with occasional undeterminable fragments of molluscan casts, corals, and echinoderms. It is a creamy-white, hard, homogeneous limestone throughout.

The evidence of these artesian wells would not of course be sufficient if taken by itself, but it is fortunately confirmed by the fact that the Vicksburg limestone constantly appears as a surface outcrop in many localities, and we have specially noticed it in Wakulla and Franklin counties, west of Tallahassee, in Marion

and Citrus counties, in Tampa Bay, and on the banks of the Manatee and Caloosahatchee rivers.

The formation in which the phosphate deposits are now found, however, is, as we have elsewhere remarked, not confined to the Eocene age, but belongs also to the Miocene epoch, and the manner of their occurrence appears chiefly to be:

First.—Original pockets or cavities in the limestones, filled with hard and soft phosphate and débris.

Second.—Mounds or beaches of loose material rolled up on elevated points, and chiefly consisting of huge boulders and large and small fragments of phosphate rock.

Third.—Drift or disintegrated rock commonly called "pebbles" distributed over immense areas, but chiefly located in Polk and Hillsboro counties and underlying Peace River and its tributaries.

As to their origin there has naturally arisen a very great deal of discussion, but although a certain number of more or less plausible theories has been advanced, it is doubtful whether any particular one has yet been generally accepted. Those which have arrested the most attention, however, may be briefly summarized in the following way:

First.—When the rocks emerged from the sea they became the roosting-places of innumerable water-fowl. If 5,000,000 of these birds each deposited no more than one ounce in 24 hours, they would produce about 300,000,000 tons of guano in 5,000 years. The phosphoric acid of this guano, when set free by various natural agencies and processes, would penetrate into the underlying porous limestone, and gradually drive off and replace the carbonic acid.

Second.—The phosphate of lime found in the various deposits in all its types and forms had its immediate origin in animal life and agency, and is a true fossil or fragment thereof. The lime phosphate was secreted by the animal either directly from the sea waters, or by feeding on lower vegetable organisms that abound in the sea. The phosphate of lime was the basis of its solid skeleton, and it belonged to the lowest type of animal life; was so closely allied, in fact, to the lowest type of plant growth, that naturalists have scarcely yet agreed as to their affinities. There are certain kinds of sponges, infusoria, and animals of lowest type, which assimilate silica either directly from the water or from their food. Others, again, secrete carbonate of lime; and still others, a horny substance, as their supporting skeleton. In each case this secretion

FLORIDA ROCK-PHOSPHATE MINES.

Remarkable deposit of "drift" or "gravel" phosphate at Anthony. One cubic yard yields about 500 pounds washed material, averaging seventy-six per cent. phosphate of lime and four per cent. oxides of iron and alumina.

and growth continue until the environments change—the animals are exterminated and a massive nodule of flint, a cliff of chalk, a coral reef, or a heavy stratum of infusorial casts or tripoli remain as the result of their life-work. This being admitted, it is not improbable that certain other species may secrete a skeleton of lime phosphate. The majority of shells, either fossil or recent, consist mainly of lime carbonate secreted by the animal; but there are some, and notably the Lingula, which are known to secrete and live in a shell of phosphate of lime.

Third.—The Vicksburg limestones contain a notable percentage of phosphate of lime, say for example three per cent, as an integral part of their composition. If these limestones were acted upon by waters sufficiently charged with carbonic acid gas, the carbonates would gradually go into solution. The greater portion of them would be thus removed while the greater part of the less soluble phosphate of lime would either be left behind in a sedimentary condition, or be washed into and deposited in fissures or caves, the limestone walls of which would be subsequently leached away.

The fact has long been known and admitted that when waters contain a considerable percentage of free carbonic acid gas they exercise a solvent action upon limestones and marls which increases in direct proportion to the porosity of the material and the amount of surface exposed. The Eocene limestones under discussion were undoubtedly extremely porous, and they certainly contained notable quantities of phosphate of lime. Combining these two with the other equally significant fact that the waters of Florida were very heavily charged with carbonic acid, the natural conditions would all appear to favor the theory to which we have given the third place, and it is therefore the one to which, with certain necessary modifications, we have given our own preference.

It has been shown that the quantity of carbonic acid in the offshore waters in various parts of the world, is somewhere in the neighborhood of five times the amount required by the lime which they hold in solution, and it is probable that the disparity becomes still greater in the highly charged waters of the land.

The following table from Bischoff's "Chemical Geology" gives the solubility of phosphates of lime in water saturated with carbonic acid gas:

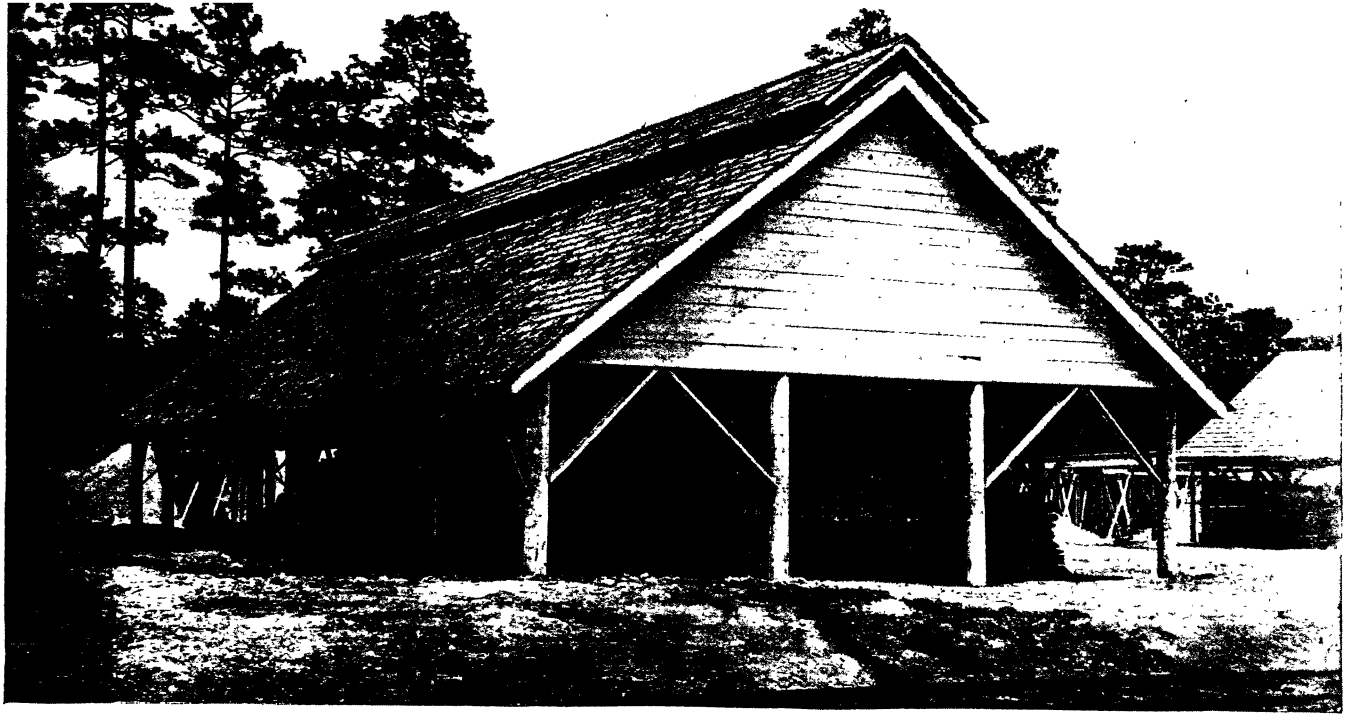
	Water saturated with CO_2 parts
Apatite dissolves in	393.000
Apatite, after brisk agitation with the liquid, in	96.570
Artificial neutral phosphate, freshly precipitated, in	1.503
Same salt, after thorough drying in air, in	2.042
Artificial basic phosphate, freshly precipitated, in	1.102
Same salt, after thorough drying in air, in	5.432
Same salt, after ignition, in	13.115
Burnt bones which had been exposed for several years and had absorbed carbonic acid	2.823
Fresh ox bones, in shavings	4.610
Fossil bones that had been buried at least thirty years	3.300

As Bischoff himself says, these figures show how remarkably the solubility of phosphate of lime varies according to its source and the kind of admixtures present. The quantity of carbonic acid requisite for the solution of bones is by no means large, and in situations where carbonic acid is copiously and continuously evolved in putrefaction their solution may take place rapidly. It is deserving of notice that basic phosphate of lime dissolves in 3150 parts of water, containing one-twelfth of its weight of chloride of sodium. The presence of chloride of ammonium increases the solubility still more. The solvent relation of water to phosphate of lime will therefore always be greater in proportion to the quantity of chlorides present.

Assuming that the Miocene waters were heavily charged with both carbonic acid and chlorides, and that they readily dissolved the carbonates and a portion of the phosphate of lime, as they doubtless did, it is reasonable to conclude that the phosphate was subsequently redeposited under conditions resulting from the lowering of the solvent power of the waters through loss of carbonic acid. If this be a correct hypothesis, the deposit of the phosphates may be accounted for in two ways; the first, as we have already said, consisted in removing the soluble carbonate and leaving a large portion of the less soluble phosphate behind, and the second consisted in adding to this residual phosphate those quantities which were deposited from the leaching solutions. Either or both processes may have occurred on an exposed surface, or they may have gone on in an interior cavity, which by continued growth they would eventually fill with laminated or massive rock. When the material surrounding the cavity was broken down or dissolved away, the massive body of phosphate of lime would remain exposed and would, while preserving the shape of the cavity, otherwise present all the appearance of a water-worn boulder. In any

FLORIDA ROCK-PHOSPHATE MINING.

Deposit of "boulder" material, in matrix of clay and soft white phosphate, worked in grades.



FLORIDA ROCK-PHOSPHATE MINING.

View of a drying shed at Dunnellon, Marion Co. The rock is built up on layers of pine wood and fired, thus insuring complete calcination.

event, it is an undoubted fact that numerous large and small estuaries were formed in the leached-out rock cavities when the Miocene waters began to recede. These estuaries must certainly have been replete with various lower forms of animal and vegetable life, and as the waters became more and more concentrated there would have taken place in them a multitude of readily conceivable processes of metamorphism. When the suspended and deposited phosphate mud or slime eventually solidified on the exposed surfaces and became dry, it was soon cracked and broken up by the splitting of the soft underlying limestones. It is then easy to conceive that the cracked and broken phosphate crust slid from the surface into yawning gaps and from one fissure to another, and that succeeding seas mixed it up heterogeneously with their deposits of drifts and shells, sands, marls, clays, and other transported material. Such portions of the broken phosphate crust as were not confined in permanent limestone fissures or caverns were very thoroughly disseminated, and were either banked up with other drift material in various mounds, or buried in depressions in conformity with the violence of the waters, or with the uneven structures of the surface to which they were carried.

Occasionally this drifting mass found its way into very deep hollows, in regions where considerable depressions were brought about by the sinking and settling of the sub-stratum. At other times it was rolled to and deposited on slightly higher points. In the first of these cases there have been found vast and complete agglomerations comparable to an immense pocket of broken-up phosphate rock, finely divided débris or soft phosphate, sands, clays, and marls, all jumbled together. In the second case the phosphate has retained the form of large boulders, some of which have weighed several tons, and all of which have been more or less mixed up with similar boulders of flint rock cemented together with soft phosphate or clay.

In the case of the land and river pebble phosphate of south Florida, we believe that they most probably originated in an exactly similar manner to the hard-rock phosphate, with the difference that the phosphate of lime which was suspended or dissolved in the mud or silt was deposited on a surface of limestone and underwent a subsequent process of segregation and nodular concretion.

The growth of peninsular Florida since Eocene times has chiefly been eastward; and the surface slopes and drainage have been in this direction. On this eastern side of the rock phosphate

belt the phosphate sediments and the materials carried in actual solution have again been deposited in the hollows of the older limestones, and have produced the well-developed beds of individual character known as plate-rock phosphate.

All these various grades of phosphate are now being exploited by regular mining and hydraulic methods over an immense area on a large scale at various points throughout the State.

In several of the hard-rock mines, notably in those of Marion and Citrus counties, the beds of phosphate have extended in many cases uninterruptedly over several acres. These beds have shown themselves to be combinations of the "original pocket" and the "mound formation," the superincumbent material or overburden being principally sand, without any admixture of phosphate and of an average depth of 8 or 10 feet. The immediately underlying phosphate rock is sometimes in the form of an aggregation of enormous boulders intermixed with boulders of flint and limestone all cemented together with thin layers of clay, and sometimes in the form of small fragments of phosphate boulders, imbedded in a white plastic or friable mass resembling kaolin. This white material is known as soft phosphate, and is, like the fragmentary rock, doubtless the result of a natural disintegration of the hard boulders by rolling, attrition, or concussion.

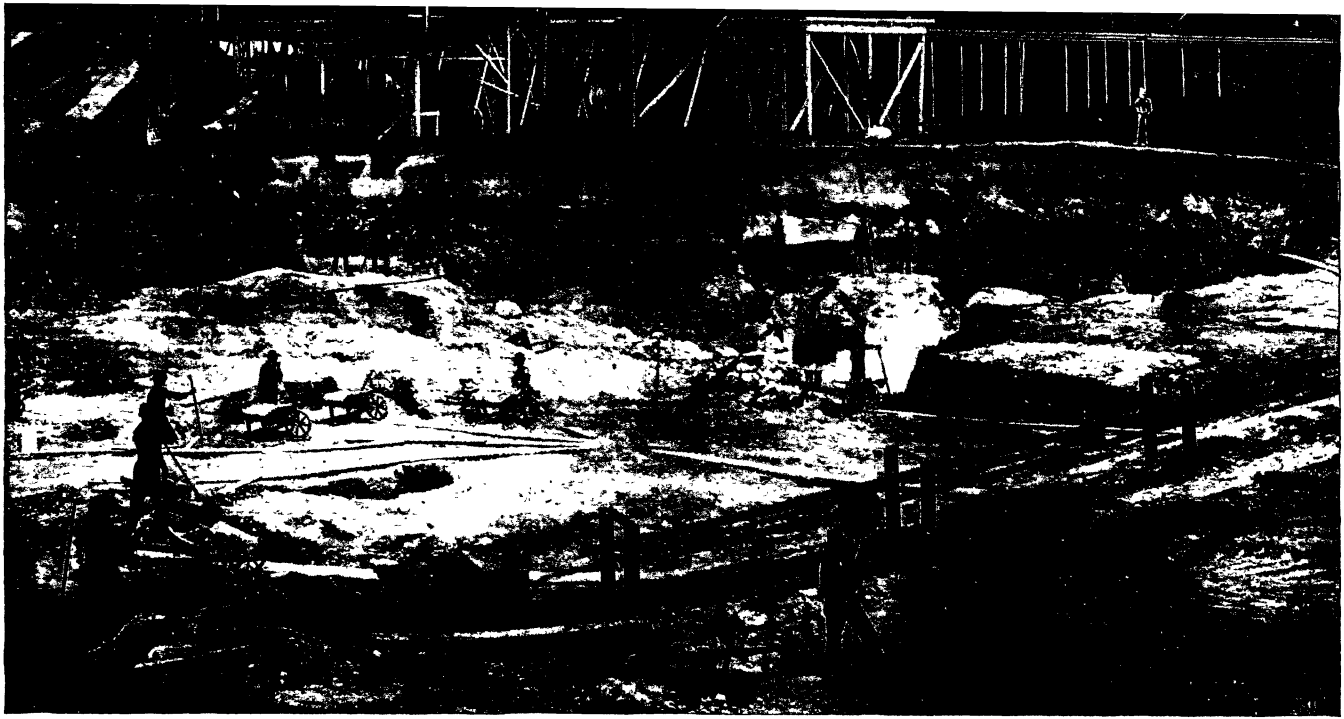
The actual thickness of these phosphate beds is too variable to be computed with any accuracy into an average, for it has been known to range from 5 to 50 feet before reaching the limestone bottom. Directly outside of the limits of these combined "pockety" and "mound" formations, the readily exploitable deposits of boulder rock phosphate frequently terminate very abruptly and give place to an unimportant drift of fragmentary material which sometimes crops out at the surface through the sand, and which may be followed in all directions over the immediate vicinity without leading to another pocket of boulders of exploitable value.

When the pockets are of any considerable depth they yield large quantities of merchantable phosphate, but they are frequently very superficial, and in some of them the phosphate is so near to the underlying limestones and so mixed up with other and valueless material as to render profitable exploitation impossible.

An excellent and indeed typical example of this superficiality is afforded by one of our own examinations, in which the geological conditions did not differ in any essential particular from those

FLORIDA ROCK-PHOSPHATE MINING.

Deposit of "boulder" material in matrix of clay and sand, Elliston, Citrus Co



FLORIDA ROCK-PHOSPHATE MINING.

View of the Dunnellon Mines in exploitation, Dunnellon, Marion Co.

we have just described. The area investigated may be thus represented :

5,120 acres of land.

A	B	C	D
E	F	G	H

Each division representing 640 acres.

Very fine phosphate indications were scattered more or less all over this tract, sometimes in the form of big boulders outcropping at the surface, sometimes in the form of small débris brought up from below by the mole or the gopher. A local "expert" had estimated that it contained millions of tons, and our own first impressions of it were of the highly sanguine order. A systematic exploration was, however, at once instituted and carried out; first by boring all over the tract with a twenty-foot auger, and then by sinking confirmatory pits at short intervals to a depth of 15 to 20 feet, according to the plan described in the chapter on South Carolina.

The result of our work was extremely disappointing, and may be briefly summarized thus :

A.—No phosphate in workable quantities.
B.—A small basin or pocket of good phosphate, covering an area of about 15 acres.
C.—No phosphate in workable quantities.
D.—No phosphate in workable quantities.
E.—Large quantities on surface, leading to a very large pocket, covering about 35 acres. Very much mixed-up material, principally phosphate of low grade.
F.—No phosphate in workable quantities.
G.—No phosphate in workable quantities.
H.—The highest point in the tract—very densely grown, big boulders of phosphate and sandy conglomerate on surface. Fifteen small pockets of phosphate, ending in limestone at a depth of thirteen feet.

The total acreage covered by these widely scattered *phosphate deposits* was set down at *eighty-three acres*, and the character, quantity, and composition of the phosphate itself, as shown by the pits dug and by the material extracted from them, were estimated after experiment to be as follows :

CHARACTER AND QUANTITY OF PHOSPHATE BED.

Boulder material, large and small, after screening	13	per cent.	of the	mass.
Débris and whitish phosphate, soft and plastic	29	"	"	"
Sand, clay, flints, and waste	58	"	"	"
	100	"	"	"

AVERAGE ANALYTICAL VALUE OF THE PHOSPHATES (AFTER SUN-DRYING).

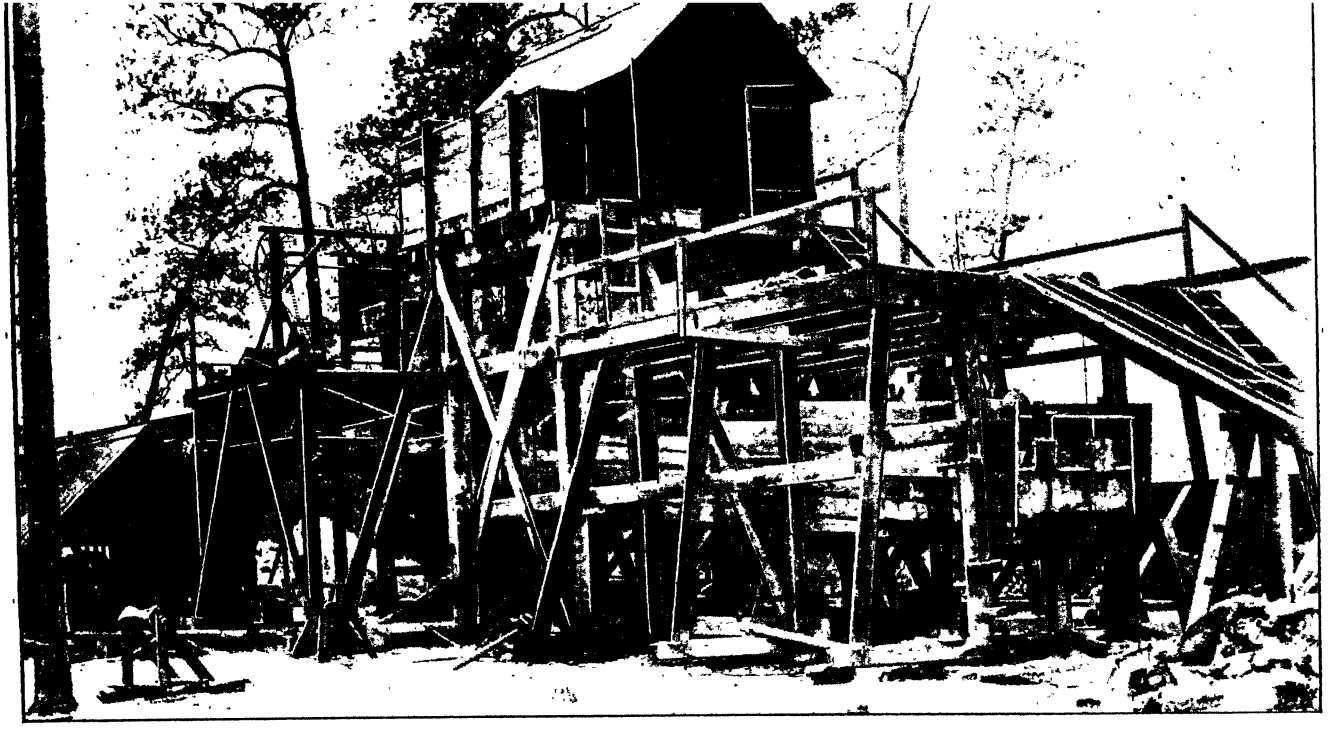
	Boulders.	*Débris, etc.*
Phosphoric anhydride (P_2O_5)	37.00	30.00
Oxides of iron and alumina (clay)	4.25	7.50

After this analysis of the boulder material had been made the remaining lumps were all broken up with a hammer into pieces averaging 1½ inches in size and very carefully washed, with constant shaking on a fourteen-mesh screen held under a stream of water. After being thoroughly dried in the sun, the washed material was put through a hand-crusher, then ground to the fineness of seventy-mesh, and submitted to analysis. The results, which have a most important bearing on the vexed question as to the form of combination in which the iron and alumina of these phosphates chiefly occur, were in this case as follows:

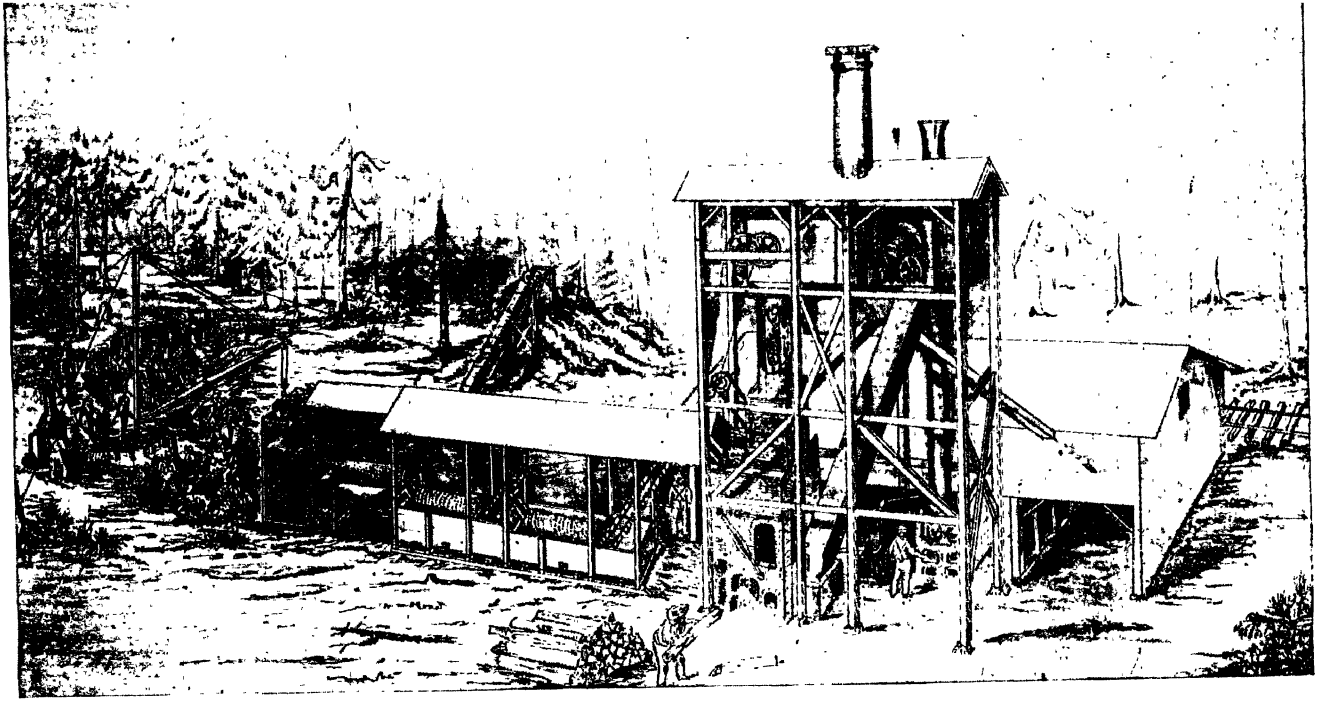
Phosphoric anhydride (P_2O_5)	38.10
Oxides of iron and alumina	1.73

The thickness of the phosphate bed varied in different places from 3½ to 27 feet, but was found to have an average of about 8 feet. Assuming that this thickness would yield, say, 5,000 tons to the acre (a conservative computation), we reach a probable total of 415,000 tons for the entire tract, of which, according to the experiments summarized above, about fifty-five thousand tons might be high-grade "boulder," containing, say, eighty per cent. of bone phosphate, and about one hundred and twenty-five thousand tons débris and seconds, containing from sixty to sixty-five per cent. of bone phosphate.

The results of this exhaustive examination led us to suggest what has now become the generally adopted plan for working the boulder deposits in such a way as to free them as far as possible from the undesirable iron and alumina, chiefly present as adhering particles of clay. This plan consists in working the mines in immense open cuts by means of hoisting engines and tramways, crushing the whole of the boulder rock to a small size by means of a stone-breaker, and passing it, together with the entire output of the mines, dirt, débris, etc., through steel shaft or log washers



MINING AND WASHING PLANT AT THE ILLINOIS PHOSPHATE COMPANY'S MINES.
(Using McLanahan & Stone's Double Log Washer and Screens.)



FLORIDA ROCK-PHOSPHATE MINING.

Sketch of The Jeffrey Manufacturing Company's plant in working order, hoisting, screening, washing and drying phosphate rock. Scale about half an inch to 6 feet.

and screens. The material is thus entirely freed from sand and clay, and is finally dried in built-up open kilns. We have found from actual experience on a very large scale, with a washer constructed by Messrs. McLanahan & Stone, of Gaysport, Pa., that by this method of mining, when economically carried out, the average cost of production does not exceed about $3.50 per ton of clean ore free on board cars at the mines, and that practically no phosphate is sent to waste on the dumps. We consider it a matter for great congratulation that this method of mining was based upon and has fully justified the results of very lengthy and exhaustive laboratory experiments, and we believe we may claim for it without exaggeration :

1. That, the product being reduced to a uniform size, the difficulties hitherto experienced in obtaining fair and concordant samples on the shipment of a cargo and upon its arrival at a port of discharge are materially lessened, if not entirely obviated.

2. That the objectionable iron and alumina being nearly always present in the original sample in the form of clay, held and secreted in the interstices or cracks of the rock, are practically all removed by the water and the agitation during the washing process.

There are at the present time a very considerable number of working washing plants, designed and erected by Messrs. McLanahan & Stone, to fulfil the needed conditions, and they are doing very excellent, successful, and economical work. The plant devised by the Jeffrey Manufacturing Company, of Columbus, Ohio, and shown in our illustration, also seems to have given very satisfactory results.

According to this latter system the boulder rock is hoisted from the quarries by a derrick, delivered to a crusher, and thence into a system of screens. The first is a dry screen, the second a washing screen, and the third a finishing or rinsing screen ; and the rock is delivered from one wet screen to the other by short elevators, and then taken from the last screen by a slow-motion elevator, so as to drain off as much of the water as possible. It is then delivered at the top of a furnace having interlapping shelves, under which the flues conducting the products of combustion to the stack are carried. While descending from one of these shelves to the other through the hopper-like aperture to the furnace, the rock is either heated to the necessary degree to dry it, or, by a retaining device at the bottom, may be kept until thoroughly calcined, after which it is delivered hot to the foot of an elevator. The flue connecting with this elevator and furnace is arranged with three con-

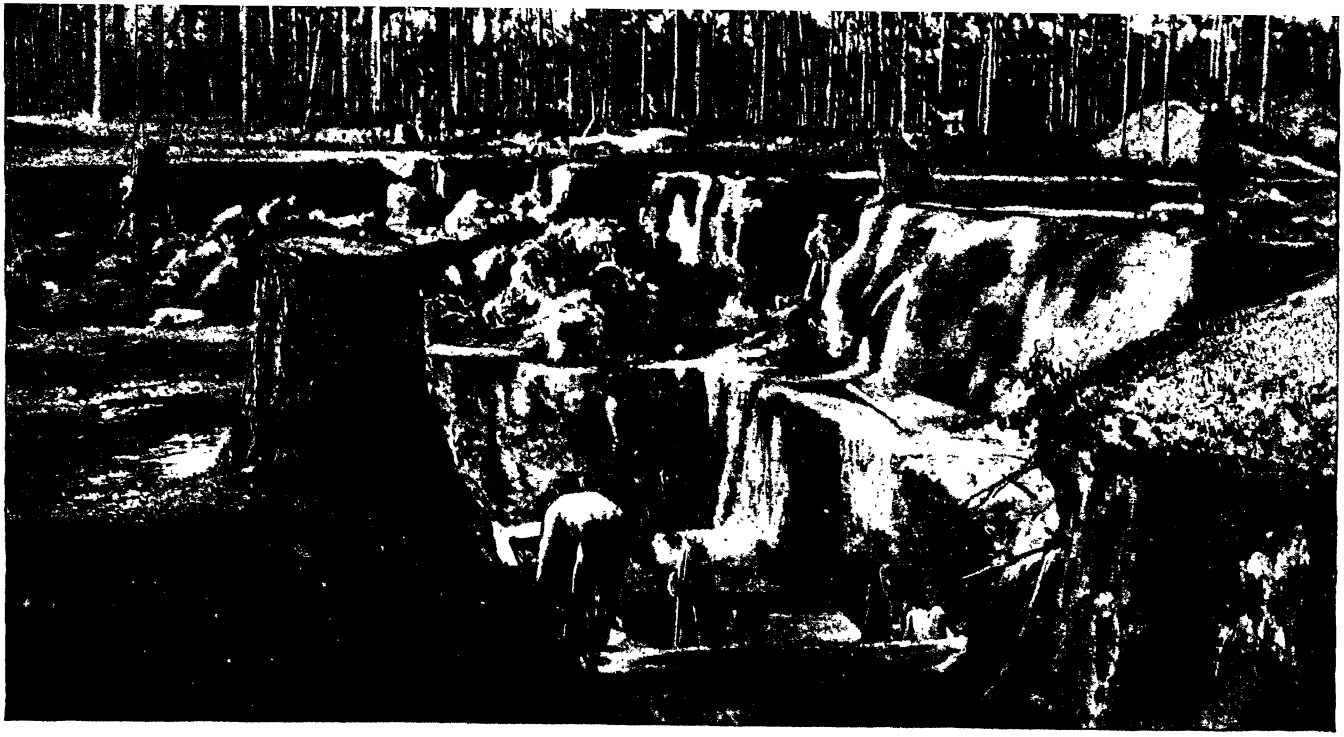
duits: one for the smoke and heat, one for the buckets of the elevator, and one for the dry-air draught. The partition between the smoke and combustion flues and that of the elevator is thin iron after reaching the height of the brick-work. The buckets are constructed of screen wire, so that the escape of vapor from the heated rock is impeded as little as possible. The partition between the bucket flue and the dry-air flue is perforated at intervals, so that the draught of dry air will produce the effect of drawing off the vapor from the buckets of heated rocks as they pass upward through the elevator-flue. The movement of the elevator is so slow that about 20 minutes from the starting at the bottom, or boot end, are required to deliver a bucket of phosphate rock at the top; after the delivery is once commenced, however, it is continuous.

The great bulk of the material from the hard-rock regions is now forwarded by rail to Fernandina, and shipped from that port to Europe. It is nearly all carried over the lines of the Florida, Central and Peninsular Company, and is discharged into their extensive and convenient elevator, whence it is unloaded directly into outgoing vessels. The average rate of freight from the mines to the port is about $2.25 per ton of 2240 pounds. A few of the mines are favorably located for the shipment of their product from Port Tampa over the South Florida Railroad, and these only pay a freight of about $1.10 per ton. The advantage which they gain in this direction is, however, generally offset by the prevailing objections to the port and the consequent demands of vessel owners for a higher ocean freight.

In those districts of Florida where no boulder or other variety of hard-rock phosphates have been discovered, and where only pebbles abound, the capriciousness of formation is much less marked, as will have been inferred from our description of its origin.

An unusual degree of regularity may in fact be said to characterize the occurrence of what is commonly known as the "land pebble" phosphate throughout a large portion of the extensive area in which it has been found.

As we have already shown, this area takes its point of departure in Polk County a little south of Bartow, and thence practically continues with a gradually narrowing tendency to within a very short range of Charlotte Harbor. Extensive exploratory work has demonstrated that it is more or less underlaid with a nodular phosphate stratum of a thickness varying from a few inches to 30 feet, with an overburden of sand and clay that may be fairly averaged at about 8 feet.



FLORIDA ROCK-PHOSPHATE MINING.

Extracting "boulder" material from matrix of sand and clay, Empire State Company's mines, Citrus Co.

FLORIDA ROCK PHOSPHATE MINING.

Phosphate piled on pine logs ready for firing before shipment.

The most important working centre for "pebble" phosphates is Peace River, which rises in the high lake lands of Polk County and flows rapidly southward into the Gulf of Mexico. Its course is extremely irregular, and its bottom is a constant succession of shallows and deep basins. Lakes Tsala-Opopka and Chillicohatchee and Pains and Whidden creeks are its chief tributaries, and we have satisfied ourselves by careful examination that they are the main sources of its phosphate deposits, since the phosphate "pebbles" are without doubt washed out from their banks and borne along their beds by the torrential summer rains.

The phosphate "pebbles," when pumped out of the river and freed from impurities and dried, vary in size from a grain of rice to about 1 inch in diameter, and they are intimately mixed up with the bones and teeth of numerous extinct species of animals, birds, and fish.

The exploitation of the "river pebble" is performed by means of a ten-inch centrifugal steam suction pump, placed upon a barge. The pipe of the pump, having been adjusted by ropes and pulleys, is plunged ahead from the deck of the dredge into the water. The mixture of sand and phosphate sucked up by it is brought into revolving screens of varying degrees of fineness, whence the sand is washed back into the river. The cleaned pebbles can be discharged from the screen into scows at the rate of about 12 tons per hour, and the product is floated down to the drying-house, where it is taken up by an elevator and dried by hot air.

The total cost of raising, washing, drying, screening, and loading "river pebble" phosphates on the cars is stated by the largest operators to be $1.75 per ton, and we believe this to be the lowest yet reached in the history of the world's phosphate mining.

It is probably a recognition of this fact that has led the Florida State government to imitate the custom so long prevalent in South Carolina, and so profitable to that State, of imposing a royalty upon all phosphates removed from navigable rivers or streams. A law regulating this kind of mining in Florida has now been passed by the Legislature and duly signed by the Governor. Under its provisions the Governor, Comptroller, and Attorney-General are constituted a board of phosphate commissioners, which board shall have the management and control of all phosphates in the navigable waters of the State. The board has power to appoint a phosphate inspector at a salary not to exceed $1,500 per annum, who will act as its executive officer.

On all the phosphates taken from navigable waters within the application of the law a royalty of 50 cents per ton will be col-

lected when the phosphate material analyzes "fifty per cent., or less, and not to exceed fifty-five per cent. bone phosphate of lime." Seventy-five cents per ton for "material analyzing over fifty-five per cent. and not exceeding sixty per cent.," and "$1 per ton for every ton of phosphate rock, etc., analyzing in excess of sixty per cent. bone phosphate of lime."

Account is to be rendered to the board of commissioners and payment of royalty made to the State quarterly.

The State grants the right to persons, either natural or corporate, to mine the navigable waters of the State within certain well-defined limits, in no case to exceed ten miles by course of stream, for a period not to exceed five years, preference being given, however, to riparian owners and to those who have commenced to mine in good faith before the passage of the act.

The bill further enacts that no person or persons shall be permitted to mine the bed of any navigable water of the State until he or they shall have first filed with the board of phosphate commissioners a bond, with good and sufficient sureties to be approved by the board and in such sum as the board shall deem proper. Mining must begin within six months from date of contract and continue to the full term of the contract, unless the phosphate or phosphatic deposit be previously exhausted.

The passage of this law has, of course, elicited a great deal of opposition, and litigation has already commenced between the State and many of the companies which claim vested rights in the river deposits. A considerable number of these companies are, however, unaffected by its provisions, which do not apply in cases of navigable streams or parts thereof that are not meandered, and the ownership of the lands embracing which is vested in a legal purchaser.

With the extremely low cost of production of the "pebble" material, however, it is hardly conceivable that so trifling a tax as that imposed by the new law can be regarded as a burden, or that it will have the least injurious effect upon the progress and profits of the industry.

The only difference between the "river" and the "land" pebbles is that the latter are of a lighter color and are imbedded in a matrix of sand and clay to which they frequently bear the proportion of about twenty per cent. by weight.

They have not yet been extensively worked and there is still some doubt as to the most economical way of winning them. Some of the large concerns in Polk County employ a floating dip-

FLORIDA PEBBLE-PHOSPHATE MINING

Dredges at work on Peace River.

per dredge, set in a deep trench or canal, which, as water springs a few feet below the surface, is deepened and extended as the deposit is removed. The entire mass of phosphate and matrix is brought up by the dredge, and, as in the case of the boulder-rock mines, is first dropped into a species of disintegrator or crusher, whence it passes on into a revolving washer mounted on the same structure. From the washer the matrix and water return to the trench, while the clean nodules are carried by a spiral conveyer to a steam-heated dryer on a barge alongside. From the dryer they fall into a revolving screen, which removes any remaining particles of adhering sand, and the now marketable phosphate is caught up by elevators and delivered on board railway cars standing on a track parallel with the trench.

Other companies are using a steam clam-shell folding dipper, operated from a car on a railroad track, which is prolonged over the land laid out to be mined. The folding lever, to which the 5-ton dipper is attached, works on a pivot and moves over a semicircle of about 25 feet. On one side of the excavation made, the overburden or dump is discharged, and on the other the phosphate-bearing material is deposited in cars on a side track. As the work progresses the steam-shovel retires, leaving behind it an enormous ditch, resembling a canal, which rapidly fills with water that is subsequently used for washing the phosphate.

The average cost of running a plant of the latter description, capable of producing from 40 to 50 tons of clean phosphate per day, is said to be about $84, made up as follows :

RUNNING EXPENSES PER DAY OF A LAND PEBBLE MINE.

Occupation.	*Number of men.*	*Daily rate of pay.*	*Total wages.*
Manager	1	$6.00	$6.00
Steam-shovel engineer	1	3.50	3.50
Steam-shovel fireman	1	2.00	2.00
Steam-shovel craneman	1	3.50	3.50
Tram-car hands and loaders	5	1.50	7.50
Washer feeder	2	1.50	3.00
Washer engineer	1	3.00	3.00
Washer fireman	1	1.50	1.50
Dry bin hands	3	1.50	4.50
Waterman	1	1.50	1.50
Extra hands	10	1.50	15.00
Total labor	27		$51.00
15 cords of wood at $2 per cord			30.00
Oil, packing, waste, etc			3.00
Total running expenses for one day			$84.00

The rate of railway freight upon all phosphates from the "pebble" region may be estimated at an average not exceeding $1.25 per gross ton, as the whole of this material is shipped either from Punta Garda or from Port Tampa and is carried from the mines by the South Florida Railroad.

The chemical composition of Florida phosphates, and more especially of those known as "hard rock" or "boulder," is far from being constant or reliable, as would be naturally anticipated in such an irregular and varied formation as we have attempted to describe. Nor is it more uniform in its physical aspect, for while in some regions it is perfectly white, in others it is blue, yellow, or brown. In many instances it is practically free from iron and alumina, but in not a few districts it is heavily loaded with these commercially objectionable constituents.

For the purposes of general illustration we present the following averages, selected from the results of several hundreds of our complete analyses, made either in Florida or New York. The samples in every case were taken from exploratory pits in different counties, and were marked before leaving the ground with full details of their origin. We have classed them as:

1. Boulders of hard-rock phosphate, or cleaned high-grade material.
2. Boulders and débris, or unselected material, merely freed from dirt.
3. Soft white phosphate, in which no boulders are found.
4. Pebble phosphate from Peace River, as sent to market.
5. Pebble phosphate from Polk County drift beds, washed and screened.

	Phosphate of lime.	*Oxides of iron and alumina.*	*Silica and Silicates.*	*Carbonic acid.*
Boulders (carefully selected, 120 samples)	80.49	2.25	4.20	2.10
Boulders and débris (237 samples)	74.90	4.19	9.25	1.90
Soft white phosphate (148 samples)	65.15	6.20	5.47	4.27
Pebble from Peace River (84 samples)	61.75	2.90	14.20	3.60
Pebble from drift beds, Polk County (92 samples)	67.25	3.00	10.40	1.70

The names of the companies thus far formed for the purpose of exploiting these phosphates in Florida will be found tabulated in subsequent pages and the total quantity of phosphate mined by them since the commencement of their operations is as follows:

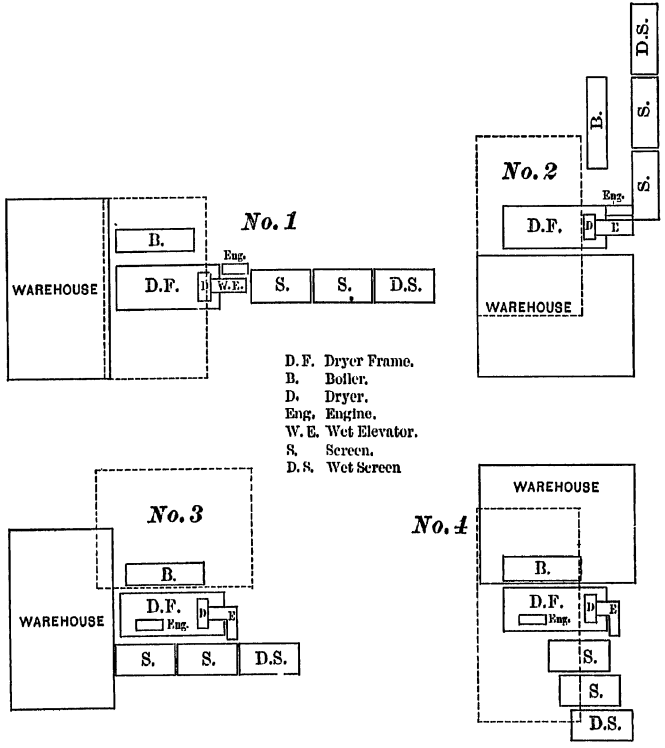


DIAGRAM OF THE VARIOUS MODES OF LAYING OUT THE JEFFREY MANUFACTURING COMPANY'S PHOSPHATE PLANT.

Year.	*Tons.*
1888	3,000
1889	4,500
1890	46,500
1891	112,500
1892	300,000
1893, estimated at	300,000

In considering the figures of this table, it is well to remember that previous to the year 1890 the average total annual output of phosphate in the United States was about 500,000 tons. Nearly the whole of this quantity was raised in South Carolina, and of it about one-third was exported to Great Britain and Germany, the balance being used at home.

It was in the year 1890 that the difficulties between the Coosaw Company and Governor Tillman came to a head, and as the temporary suspension of this company's gigantic operations, pending legal proceedings, threatened a considerable decrease in production, foreign and domestic buyers became anxious to secure their needed supplies, and sellers advanced their prices.

To the initiated this was an intelligible and natural situation. On the one hand there was a probable temporary deficiency of 100,000 tons by the Coosaw Company; on the other there were the customers of this company anxious to supply their needs and ready to abide by a rise in price rather than be left unsatisfied. A fictitious activity was thus imparted to the industry, of which few, if any, of those who rushed into the Florida fields took the trouble to ascertain the true inwardness. To these eager speculators only one phase was prominent: phosphates were in demand, and there were millions of tons in Florida ready for exploitation at an exceptionally low price and of exceptionally high quality.

The interesting facts—that the present consumptive capacity of the entire world for mineral phosphates does not attain more than 2,000,000 tons, including all kinds and qualities; that two-thirds of this quantity were being produced in other countries, from mines almost as productive as our own; that South Carolina might be equal to any demands we might make upon her—were all ignored or disregarded, and thus company succeeded company; exaggerated values were placed upon Florida lands; the costs of raising, preparing, and carrying the phosphate to market or to a shipping port were all ridiculously underestimated, and in lieu of looking to our own agriculture for an outlet and awakening the interest of American farmers, general attention was turned

to Europe as a more proper, because supposed unlimited, consumer.

The result of such a "boom" and of such ignorance has been widespread and deplorable. The foreign buyers, who were at first so sceptical about Florida phosphates, at length became seriously alarmed at their abundance, and, so far from being in anxiety as to their future supplies, soon saw themselves menaced with a glutted market and realized the impossibility of finding an outlet in any of the ordinary channels of trade for such a flood of material as that with which they became threatened. The remunerative and hitherto firm prices of phosphate therefore gradually gave way, buyers became more and more unreasonable in their demands and stipulations as to quality, and the Florida miners are now confronted by quotations which, having continually weakened under their own ill-advised efforts to create trade, now stand at a limit which has closed most of their mines. In addition to this the imposed conditions and guarantees as to quality have almost made business impossible, since they have left the miners at the absolute mercy of their foreign buyers, many of whom avail themselves of a very slight discrepancy in quality to either accept or reject the cargoes consigned to them, in accordance with the prevailing tendency of the market.

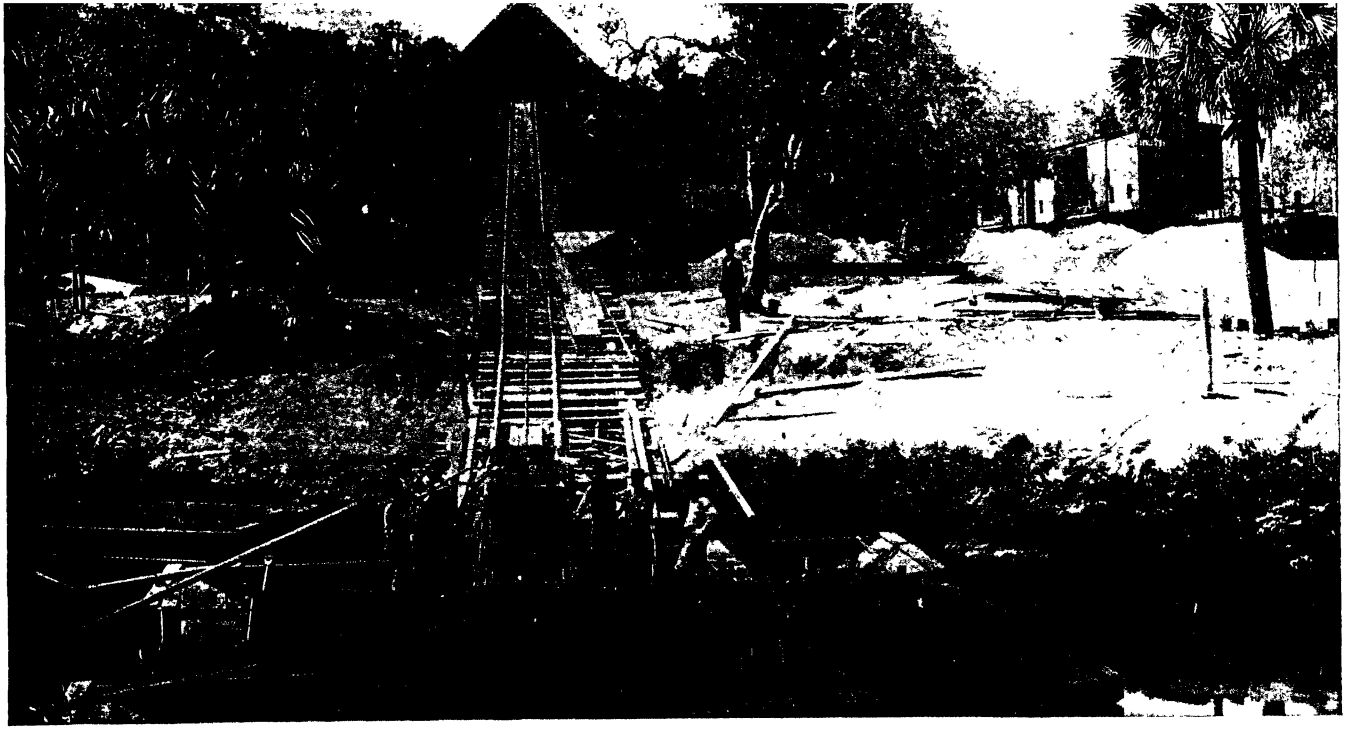
If the "boom" had resulted in any serious increase in the consumption of American phosphates, to the detriment of foreign products, either at home or abroad, we might have been satisfied even though prices were thereby lowered and mining profits reduced, but a careful and impartial study of figures shows that no such enormous increase has in reality taken place.

In the year 1890 the total sales of American phosphates from all sources amounted to about 600,000 tons, and of this quantity South Carolina produced 537,000 and Florida 46,500 tons.

The average prices for the same year were $7 per ton for rock containing sixty per cent., and $12 per ton for rock containing seventy-five to eighty per cent. phosphate of lime, both free on board outgoing vessels.

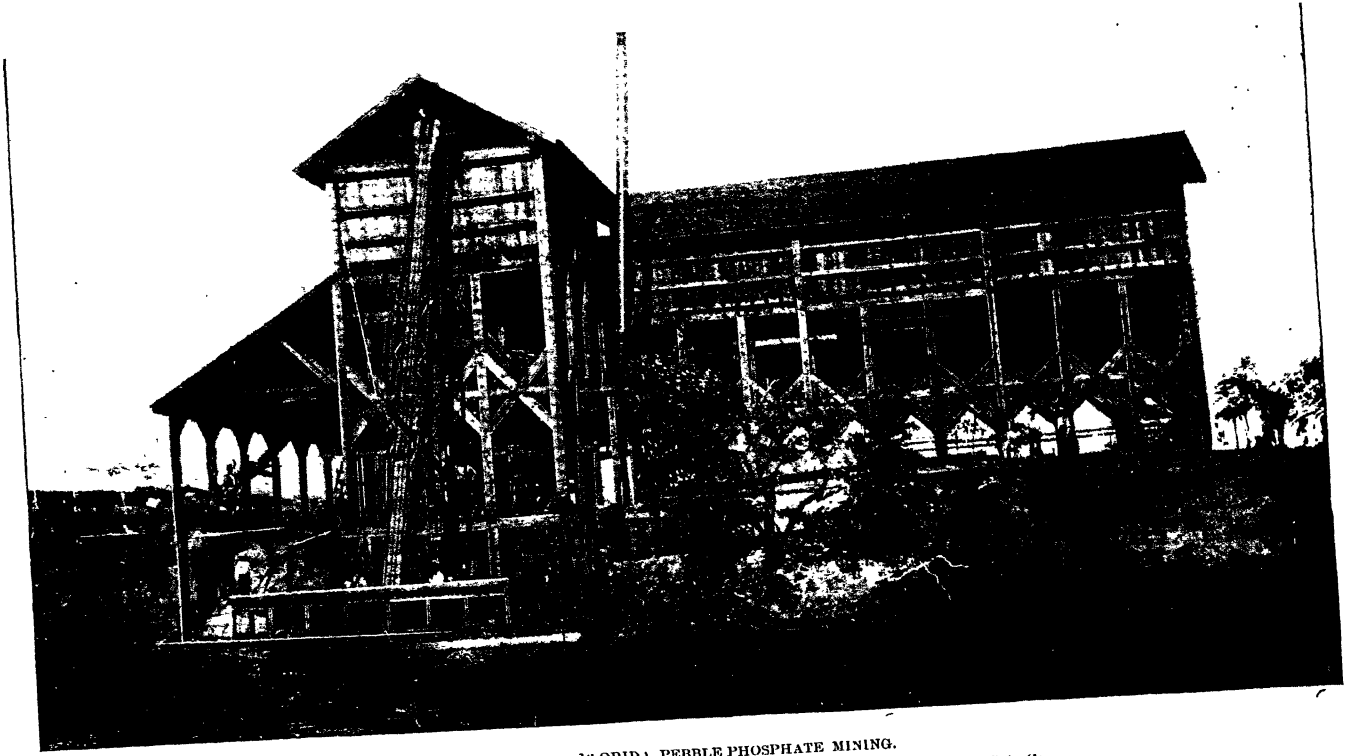
During the year 1892 there were sold nearly 700,000 tons, of which South Carolina produced 350,000 and Florida a little over 300,000 tons. The actual surplus in the total sales was therefore less than 100,000 tons, and yet this was sufficient to break the markets of the entire world, and to reduce the prices to $4.50 and $6.50 per ton for the same respective qualities.

This remarkable disturbance caused by so small a surplus (a



FLORIDA PEBBLE-PHOSPHATE MINING.

Unloading the phosphate barges at the works of The De Soto Phosphate Co. on Peace River.



FLORIDA PEBBLE PHOSPHATE MINING.

Elevators and drying works of The Peace River Phosphate Co., Arcadia, De Soto Co.

large portion of which was of exceptionally high grade and good quality) graphically illustrates the present want of flexibility in the fertilizer markets, and, in our opinion, not only argues badly for the immediate future, but should be a significant warning to our Florida producers not to further overstep the bounds of prudence.

How and when the disturbed equilibrium can be restored now that we are at war with all the other phosphate producers of the world, and now that we are so completely in the hands of the foreign buyers, and whether phosphate mining can again become one of our really profitable undertakings, are serious problems, but it is certain that there are too many mining companies who have not sufficient financial strength to stand out firmly for a juster protection of their rights, and that we must look forward to the collapse of a large majority of these before entertaining hope for any sensible relief.

The operation of the law of supply and demand is always absolute and inflexible, and this must be fully appreciated ere the future of Florida as a phosphate producer can be established on a commercial basis. Directly the applicability of this law is fully realized, her miners will not only continue to rank as the largest contributors to the world's necessities, but will be able to protect themselves against unfair dealing and always then command sufficiently remunerative prices to repay them for the expenditure of capital and labor without incurring the absurdly unbusiness-like risks to which they are now exposed and which must inevitably lead to bankruptcy.

A complete list of Florida Phosphate Mining Companies will be found on pages 179 to 181.

CHAPTER VI.

SULPHURIC-ACID MANUFACTURE.

UNTIL Mr. Rodwell published his book, "The Birth of Chemistry," we had always been led to believe that the discovery of sulphuric acid was due to Basil Valentine, but we have now reason to suppose that it was known long before his time.

It was reserved for one Gerard Dornaeus to describe with tolerable exactitude what it really was, and this he did in a pamphlet published in the year 1570.

English makers originally prepared it by burning copperas (proto-sulphate of iron) in brick ovens at a high temperature, and condensing the vapors which distilled off as an impure oil of vitriol, the commercial value of which was $1000 per ton. This process gave way to the use of sulphur and nitre, burnt together in enormous glass globes and concentrated by boiling in glass retorts, the product being called "oil of vitriol made by the bell."

Passing on by successive stages, at which we need not stop, we arrive at the year 1746, and find the first leaden chamber erected in that year in Birmingham by Messrs. Roebuck and Garbett, the proportions of raw material employed being seven or eight pounds of sulphur to one pound of saltpetre. This mixture was placed upon lead plates standing in water within the chamber, and was ignited by means of a red-hot iron bar thrust in through a sliding panel in the wall.

Shortly after this time came the introduction of a separate apartment for burning the sulphur in a current of air, which was regulated by a slide moving in the iron furnace-door, the vapors being taken off through the roof into the adjoining chamber.

Progressively and finally, the industry in Europe has now reached a point which may be almost considered perfect, there being little room for improvement in works constructed to comply with all the requirements of modern progress and modification.

In order to make ourselves completely understood by those who know little or nothing of the subject, we have prepared the annexed drawing of a modern sulphuric-acid works, and may state that when sulphur (S) is burnt in air it combines with the oxygen

of the latter, and sulphur dioxide is formed (SO_2). If this gas be brought into contact with nitric-acid vapor (HNO_3) and steam (H_2O), a combination takes place resulting in the formation of sulphuric acid and nitric oxide, thus:

$$3\,SO_2 + 2\,HNO_3 + 2\,H_2O = 3\,H_2SO_4 + 2\,NO.$$

The nitric-acid vapor is produced by heating a mixture of nitrate of soda and oil of vitriol in an iron pan contained within the brimstone or pyrites burners, and it is carried into the lead chambers simultaneously with the sulphur dioxide by means of a well-regulated air current. Reduced, as we have seen, to nitric oxide, it does not remain in this form, but immediately combines with the free oxygen introduced by the air-current and becomes nitric peroxide (NO_2). Assisted by the presence of steam, it thus constantly enacts the part of an oxygen-carrier to the sulphur dioxide, as may be gathered from the following figures:

$$NO + O = NO_2$$

Nitric oxide + Oxygen = Nitric peroxide

and—

$$NO_2 + SO_2 + H_2O = H_2SO_4 + NO.$$

Nitric peroxide + Sulphur dioxide + Steam.

And so oxidation and reduction go on, and the circle of operations is complete and continuous.

The air of the atmosphere contains about seventy-nine per cent. of nitrogen and about 20.90 per cent. of oxygen in every 100 volumes. This nitrogen plays no part at all in the changes we have described, and it hence follows that the required oxygen is accompanied by four times its volume of an inert gas which merely serves to fill up the chamber space and which calls for immediate and steady removal in order that the working elements may have fair play. At one time a simple chimney arranged at the end of the works, opposite to that at which the gases enter the chambers, was deemed sufficient, but it was soon discovered—to the cost of the manufacturer—that the nitrogen, in itself escaping, carried off with it a large share of the nitric oxide. As the preservation of this latter gas is so important a factor in the economy of the industry, means had to be devised whereby it could be saved without inconvenience, and these means were duly provided and are now universally employed, as we shall presently see.

From the commercial standpoint of economical production, the chief questions that have to be seriously considered by fertilizer

manufacturers who contemplate the erection of an acid plant may be briefly summed up in the following manner:

(*a*) Of pyrites and brimstone, which is the most economical and best source of sulphur?

(*b*) If the preference be given to pyrites, what kind of furnace or burner is best adapted for effecting its complete combustion, including the "fines"?

(*c*) What are the best dimensions to accord to the leaden chambers in which are combined and condensed the gases induced by this combustion?

(*d*) How may the maximum results be produced from the ore at a minimum expenditure of nitrate of soda?

(*e*) How to dispose of the residual cinders after desulphurization in order to lessen first cost.

Of the first problem, the commercial aspect is the only part with which we need to deal, for it is at last understood and, if somewhat reluctantly, generally admitted, that from a pound of sulphur, whether it be taken in the form of pure brimstone or in combination with some mineral as a bisulphide, the same quantity of sulphurous-acid gas, generated by its combustion, will be obtained.

From a purely scientific and theoretical point of view, and speaking with that impartiality which we are called upon to observe, there can be very little doubt that if all things were equal there would be no room for hesitation in awarding immediate preference to the cleaner, purer and in every way simpler brimstone; and we must even go so far as to admit that inasmuch as very few, if any, of the pyrites ores hitherto discovered and worked are absolutely exempt from all traces of arsenic, there are certain branches of chemical manufacture in which it would be unadvisable, and others in which it would be in the highest degree dangerous, to use them. These, however, call for the employment of but a very insignificant quota of the gigantic total annually required for the great chemical fertilizer industry, in which a trace of arsenic in the sulphuric acid employed is a matter of indifference.

We may therefore leave the interests of small works where only fine or medicinal chemicals are produced, or where only comparatively small quantities of acid are required, out of the question.

In comparing the relative cost of sulphuric acid derived from brimstone or pyrites, it must be borne in mind that in the latter we

have to deal with two very distinct species of sulphides—those containing little or no copper and those bearing it in proportions varying from one and a half to five per cent. Ores of the second category will, as it is hardly necessary to say, always be preferred as a source of sulphur when other things are equal, and will, from that very fact, serve the general purpose of keeping the price of brimstone within reasonable limits. They are now almost exclusively used by the larger European chemical makers, who, being compelled from lack of domestic material to import their pyrites, have adopted the copper-bearing ores of Spain and Portugal, and by a very slight addition to their working plant, recover from the cinders the copper, silver and gold, and apply the proceeds of the ready and profitable sale of these metals to the reduction of first cost.

There are, fortunately, a few cases where our own intelligent manufacturers have kept pace with the times and obtained notably brilliant results by using pyrites and adopting modern processes, but these only serve to bring into more prominent notice the lack of enterprise and energetic initiative so clearly apparent generally throughout the country.

As regards the purely iron ores, dependent for their value entirely upon their sulphur contents, the greatest, if not the only, bar to their more extensive application by our manufacturers, is probably the distance by which the centres of consumption are separated from the mines. The actual cost of raising and rendering them suitable for the market would appear never to exceed an average of $1.50 per ton, whereas the average cost of transport to all industrial centres is more than double that amount.

If, after making all deductions for every possible source of loss, their actual sulphur contents be estimated at forty per cent., and if their cinders be treated as a valueless factor, it follows from this that while in the vicinity of the mine the maximum cost of pyrites-sulphur would be only $5.75 per ton, the price of railway and other transportation is so great that under normal market conditions it no longer offers great advantage over imported brimstone upon reaching the consumers' kilns.

The question of freight being, therefore, such a momentous one, it is worth while to consider whether the railroad charge upon a finished fertilizer would be less onerous than that applied to the raw product, and if so, whether the erection of acid works on or near the pyrites mines would not be the surest means of turning an important source of sulphur to profitable account.

It would, of course, be folly to expect all those who are now in the fertilizer trade to become owners of good pyrites mines, but this fact need in nowise prevent them from erecting works near such mines in order to profit by whatever advantages are to be derived from using the brimstone substitutes. Let us therefore examine what those advantages actually are.

To commence with the furnace. The various forms introduced during the past few years for burning pyrites in England, France and Germany by Spence, Perret-Oliver, Juhel-Maletra, Gerstenhoefer and others have all been accurately described by popular writers, and it will suffice for present purposes to point out that the principal conditions to be realized with either lump or fines are:

First.—To generate and convey to the lead chambers a maximum of sulphurous acid and a minimum excess of atmospheric air.

Second.—A combustion so perfect that less than one per cent. of sulphur shall remain in the cinder.

Third.—To avoid any distillation of the sulphur or the formation of ferrous sulphide (FeS).

The necessary oxidation of the iron and the consequent proportionate increase of the superfluous nitrogen carried by the air in the mixture of gases, cause the volume of the latter, produced by burning pyrites, to be much greater than that proceeding from the combustion of pure brimstone, and it will be hence understood that the proper regulation of the air-supply—important under any conditions—is especially so when pyrites are employed.

The gases derived from pyrites are known to move only at the rate of about one foot per minute, and it therefore follows that they remain sufficiently long in the chambers to become so intimately and thoroughly mixed that any attempt to give a specific direction, either to the manner of their entry or their exit, becomes unnecessary.

According to theory, only three molecules of oxygen need to be admitted into the furnaces, two for the formation of sulphurous acid and the third to transform the latter into H_2SO_4. For one kilogramme of ordinary brimstone this would require 1500 grammes or 1055 litres of oxygen, or 5275 litres of atmospheric air; the amount of air necessitated by burning the same quantity of sulphur in iron pyrites being, according to the same calculation, 6595 litres.

In practical industry, however, Mr. Schwarzenberg has shown that these figures do not suffice, and that it is necessary to intro-

duce 6199 litres of dry air in the case of brimstone and 8114.9 litres in the case of pyrites, each being calculated on the basis of 0° C. and a barometric pressure of 760 millimetres. These figures serve to demonstrate that the quantity of sulphur to be profitably burned per cubic foot of chamber space will fluctuate with the higher or lower situation of the works.

The ingenious differential anemometer invented by Pecles and modified by Fletcher, and the beautiful and simple apparatus for analyzing the chamber gases designed by Orsat, have so facilitated the general process that an exactly proportioned current of air may now be measured out to meet the varying requirements of both situation and material employed. An example of this is afforded by Buchner's careful analyses, which show that the quantity of sulphurous-acid gas passed from the burners to the chambers varies from six to eight per cent., according to the nature of the pyrites, the construction of the furnace and the management of the air-supply. His greatest average by careful working was as follows: Sulphurous acid, 6.07; oxygen, 7.18; nitrogen, 86.74. The sulphurous acid requiring only 3.03 volumes of oxygen for its transformation into H_2SO_4, it will be seen that after subtracting this quantity from the above total there still remained 4.15 volumes to pass away with the nitrogen into the atmosphere, and the greatest watchfulness should be invariably observed by chamber managers to keep as nearly as possible within these proportions.

In some of the works where pyrites ores are burned, it is still customary not to convey the hot gases from the burners directly to the chambers, but to previously cool and at the same time cleanse them from the dust by which they are generally accompanied by causing them to pass from the flues into an upright brick stack, carried from an independent foundation to about 10 feet above the level of the furnace arch. From this they enter a range of cast-iron pipes 2 feet 6 inches in diameter and 27 feet long, in three lengths, cast in two halves, and each provided with a man-hole to facilitate cleaning.

These pipes are fitted into a tunnel of lead 5 feet square and 40 feet long, connected at its opposite extremity with the acid chamber by a seven-pound sheet-lead pipe of about 1½ feet in diameter.

Intelligent and thoughtful managers have now discarded this antiquated system in favor of a far simpler and more rational

arrangement of their plant, which we have endeavored to broadly outline in our illustration on opposite page, and at which a critical glance will be interesting.

Acid Chambers.—The subject of chamber construction is well worn, if not exhausted; their form and size have long been bones of contention over which certain wiseacres, with plenty of time for useless discussion, have growled *ad nauseam.* After a very varied experience and careful inspection of many working systems, we have concluded that the required object—*i.e.*, the proper condensation of the gases—can take place equally well in one large chamber as in a series of two or three, and that a choice of either is essentially a matter of personal taste and personal opinion. A very excellent arrangement will be found to consist in a set of two, adopting as favorable dimensions 125 feet long by 24 feet wide and 18 feet high. The connections are made by a fifteen to eighteen inch diameter lead pipe hung from the roof, with a good fall at its end to prevent the accumulation of any condensed acid.

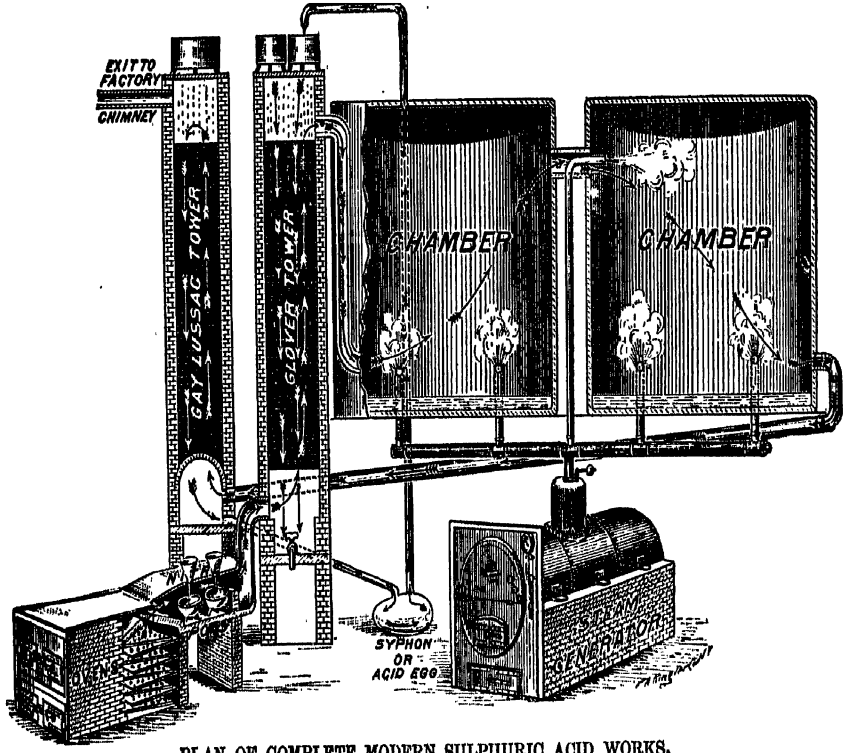
As to the necessary thickness of lead, there is almost as much diversity of opinion as upon the dimensions of the chambers; but remembering that a good chamber, properly started and soundly built, should last from ten to twelve years, a happy medium may be attained in this direction by adopting seven-pound lead for the first and six-pound for the second.

The amount of chamber room should in no case be less than 20 cubic feet for every pound of sulphur consumed.

The pressure of steam should be as evenly distributed as possible, and the faulty system sometimes adopted of introducing it from a single jet, which can only play upon one portion of the gases, must be carefully avoided. Since of every 100 tons of chamber acid produced one-half consists only of water originally injected in the form of steam, it has been urged by Dr. Sprengel that this warm steam unnecessarily expands the bulk of the gases, instead of lowering their temperature, and causing them to shrink in volume.

To obviate this inconvenience he has therefore suggested the use of a spray of cold water, to be forced into the chamber by a pump of his own invention; but the device, while ingenious, does not work well and has not been generally adopted.

The preferred method is to inject steam into the entrance end of the chamber and into its side rather more than half the way along.



PLAN OF COMPLETE MODERN SULPHURIC ACID WORKS.

The surest means of accurately knowing what is going on in the chambers is afforded by the provision and maintenance in proper condition of "drips" and "caps." This is a well-established fact among old and experienced acid-makers universally.

The best apparatus for taking drips consists of a small lead dish placed within the chamber upon a 15-inch diameter earthenware pipe, about 3 feet high, and at about 1½ feet from the side. A small half-inch lead pipe, shaped like an S, is fixed into the bottom of the dish and pierces the chamber side, setting with its mouth over a leaden basin standing upon a leaden ledge outside. The liquid acid passes as it is formed through the siphon, drips into the basin and, overflowing upon the ledge, is carried back again into the chamber by a small pipe.

Two drips should be arranged in each chamber of the set, at equal distances from each other, and the contents of the basins will constantly represent the nature of the acid and indicate its strength, nitrosity, etc., at any moment. Certain openings should be left in each chamber; a man-hole, and a small hole near the end for sampling. A couple of windows will also be useful, one fixed in the darkest side, about five feet from the ground, and the other in a direct line with it upon the top.

The light shining through these windows reveals to an experienced eye the exact condition of the gases.

The following indications are furnished by the caps of the chambers as to what is going on within, and are worthy of note:

When one of those covering the first chamber is slightly lifted the gases should rush out with great force. This should become less noticeable or almost disappear in the second chamber.

If the inside of the cap be quite dry and covered with small crystals, which, upon being moistened, turn green, the evidence is certain of an insufficiency of steam.

If, on the contrary, it be dripping wet, it is equally certain that the steam is in excess, and in either case the remedy is obvious and at hand.

The regulation of the supply of nitre, after that of the draught, is an extremely important point, a mismanagement inevitably entailing one of two evils:

First.—If the quantity supplied be too large it ruins the lead and excludes all possibility of profitable working.

Second.—If the quantity be too small there is an inevitable escape of sulphurous acid.

Volumes might still be devoted to a discussion of the reactions which go on between the gases in the chambers, and, from a truly scientific point of view, few questions are of a more absorbingly interesting nature. Our present purpose, however, of pointing out how to avoid accidents or trouble in what is really, when properly understood, a very simple and natural process, will best be served by briefly summarizing a few leading facts.

The nitric acid used in the process plays no other part, as we have previously explained, than that of carrying from the oxygen of the air to the sulphurous acid, the necessary atom of the former by which, with water, its transformation into sulphuric acid is effected, and consequently whatever be the manner of its entry, it is eventually discharged from the chambers in its original form. This being allowed, it becomes immaterial whether it is introduced directly and separately into the chambers, as is customary in many large European works, by means which have frequently been described, or whether it is sent in by the older, more economical, and certainly simpler system of "potting."

If the gases reach the chambers with a due excess of oxygen and there meet with a sufficiency of steam, none of the nitrogenous compounds will disappear.

Should steam, however, be absent, there must naturally be formed a nitro-sulphuric compound, which will prevent any reaction between the sulphurous acid and the oxygen by using up the nitrogen for its own condensation.

If the entering gases are deficient in oxygen, no sulphuric acid can be formed, owing to the fact that the nitrogen compounds are reduced in rapid succession to bioxide and protoxide. If, on the other hand, they contain too little sulphurous acid, the nitrogen compounds are transformed into nitric acid by the steam, and in this state exercise a violent and destructive action on the lead.

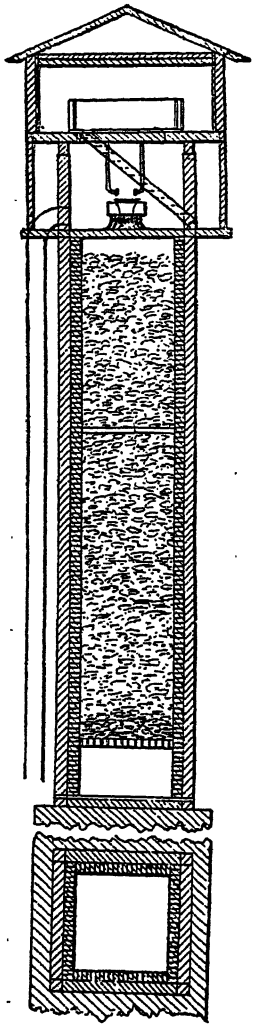
With the display of only ordinary care and intelligence, however, there should be little chance for any of these mishaps, and a simple glance at regular intervals through the side windows or a slight removal of the caps will always insure against them.

The gases in the first working chamber must invariably be white, while those issuing from the last cap of the second chamber must be of a very deep red and emit strong nitrous fumes.

We know from experience that the gases allowed to pass away from well-managed factories do not contain more than a maximum of five per cent. of oxygen, and we also know that when the red

color of the last chamber lessens or fades away, it is because of the presence of sulphurous acid, which, if it were allowed to pass into the absorbing tower, would not only denitrate the nitrous acid, but would cause the dissipation of all the recoverable nitrogen compounds.

A sufficient attention to details which, if small in themselves, are of the highest importance to the results, will bring a set of chambers in a very short time to a state of perfect working order, but it is positively essential that the operations be presided over by a competent superintendent, who, in addition to a frequent examination of the furnace cinders as a check upon the burning of the ores, should also determine by a rough analysis of the gases every day at their entry into, as well as at their exit from, the chambers, the approximate quantity of sulphurous acid contained in the one case and the amount of oxygen in the other.



SECTIONAL VIEW OF GAY LUSSAC OR ABSORBING TOWER.

GAY-LUSSAC TOWERS.

The solubility of nitrous acid in oil of vitriol containing less than four molecules of water was first taken advantage of by the distinguished French chemist, Gay Lussac, who invented the columns which bear his name, and with which even those who still disdain their use are not unfamiliar. The tower shown in the figure is a very practical form, and it must be built of eight-pound sheet-lead and should be from 40 to 50 feet in height, with an interior diameter of from 5 to 6 feet, or such other dimensions as are necessary to insure a cubical capacity of about two per cent. of the entire chamber space.

Either a brick or a wooden framework may serve as a support, but the foundation must be solid and the tower itself kept plumb and completely accessible to the air.

The packing must be carefully attended to, the proper plan being to commence with a few of the best fire-bricks at the bottom, following this with a couple of feet of large, chemically clean, pure flints, and finishing up with large lumps of hard-burnt oven (not gas) coke, the latter being not only an admirable absorbent, but also extremely cheap and sufficiently light to obviate any danger from lateral pressure. Into the exit-pipe are fitted very small glass windows, through which it will be satisfactory occasionally to note that the escaping gases yield no red fumes by contact with the air. A few feet above the tower is placed a cistern, which, by means of a properly regulated tap, supplies the cold, absorbing sulphuric acid of a strength equal to 62° B., and the great point to be attained is the maintenance of such a perfect and equal distribution in the form of a drizzling rain that not a particle of the ascending gases may escape its contact. A convenient sampling arrangement is connected with the tank at the bottom, and the nitrous vitriol is frequently tested by adding to a small sample a quantity of very cold water, when, if the absorption has been complete, large volumes of red fumes will be thrown off. The liquid is pumped from the tank to the Glover tower by means of the "egg," as hereafter described.

THE GLOVER TOWER.

This remarkably ingenious and valuable addition to the sulphuric-acid plant is named after its disinterested inventor, Mr. John Glover, an English chemist, and is to be shortly but accurately described as—

First.—A most perfect, rapid, and economical concentrator of chamber acid.

Second.—An absolute denitrator of the nitrous vitriol.

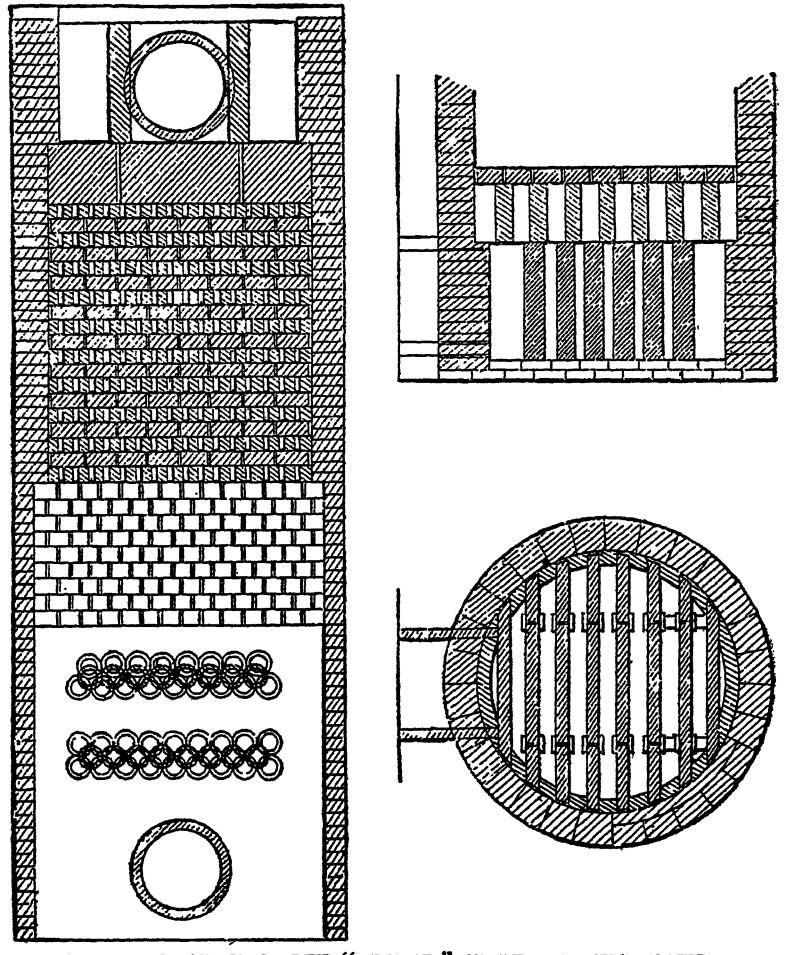
Third.—An adjunct *sine qua non* to the Gay Lussac tower.

That it should still be far from universally used or even known in this country is an extraordinary and regrettable fact, which affords sufficient reason for here devoting a certain space to an exposition of its value.

The erection of a Glover tower, while not a difficult matter, nevertheless requires very careful study, sound judgment and considerable knowledge of the functions it is expected to fulfil.

Occupying an intermediate position between the pyrites furnaces and the chambers, it receives the whole of the sulphurous and nitrous gases arising from the combustion. With a height of 30 feet

for lump pyrites and about 40 feet for "smalls," and an external diameter of 10 feet square, its foundation must be solid and its outer framework offer no impediment to a free circulation of the air. A very good form is shown in the accompanying illustration, and



SECTIONAL VIEWS OF THE "GLOVER" OR DENITRATING TOWER.

its construction is extremely simple. It has a framework of iron, lined throughout with twelve-pound sheet-lead without cross-joints. This is in its turn lined with small glass cubes and pounded glass-filling, to a thickness varying from a foot to a foot and a half. The

dish destined to receive the hot concentrated acid must be of twenty-five pound lead and have a well-formed lip, a loose sheet of lead being placed over its bottom to prevent injury from the linings. The cast-iron gas-pipe leading from the furnace projects a little above the dish some 8 or 9 inches into the tower, and directly beneath an arch built either of pure quartz or glass bricks, levelled up with small lumps of pure silica or the broken-up ends of old bottles. Upon this arch comes the packing, and here we enter into the dangerous domain of discussion and disagreement, where, while all managers agree in admitting the utility of the tower, all have pet theories as to the manner in which it is to be lined and packed in order to wear well and be turned to profitable account.

In a tower which has now been continually at work for nearly four years, and with which we are well acquainted, there are first placed upon the arch about 8 feet of open packing, with first-class fire-bricks, into the interstices of which is loosely distributed a sufficient quantity of minute siliceous pebbles.

Next comes about 3½ feet of chemically clean and pure flints of moderate size, and finally, up to within about five feet of the cover (which, together with the distributing apparatus, is the same as that described in the Gay-Lussac tower) come successive layers of the best hand-picked hard-burned oven-coke.

Immediately below the cover is an exit-pipe 3 feet in diameter, leading to the chamber with a considerable fall, while upon the top of the tower are two tanks placed side by side and suitably covered, but accessible to the cooling influence of the air. Into one of these tanks is pumped the whole of the acid from the Gay-Lussac tower, as we previously remarked, and into the other all or any part of the 50° B. acid from the lead chambers.

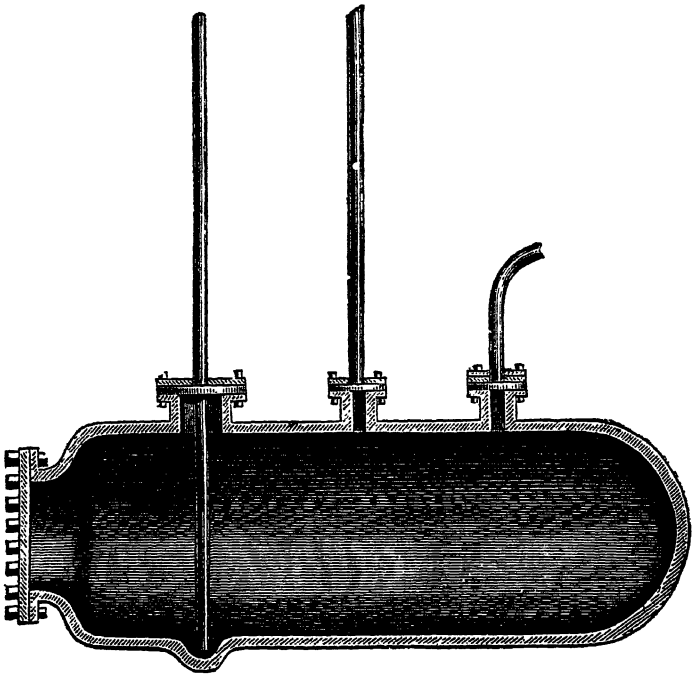
Pipes lead from each tank to a reaction wheel under the cover of the tower, whence, with the same cautious observance of minute and equal distribution already insisted upon in the case of the Gay-Lussac tower, the two liquids, made to meet and combine in equal proportions, trickle downwards.

We have seen that the acids from the chambers and the bottom tanks must be continually hoisted to the cistern on the summit of the towers, and it has been demonstrated that compressed air will carry them to any height, while exercising no decomposing action on the liquids.

The description of siphon or "egg" (as it is commonly called)

best adapted to the purpose, is shown in the illustration, and is made of thick cast-iron, shaped something like an English soda-water bottle.

It is placed in position upon a somewhat lower level than the bottom tanks, requires no lead lining, and is closed at one end by a man-hole door of wrought-iron. On its top side are provided three flanged openings fitted with a corresponding number of pipes



ACID-SIPHON, OR "EGG."

—one for the blower, one for the acid charger, and the third, which extends right through to a hollowed-out space in the under side, for delivery. Valves and cushions are fitted to the pipes leading from the tanks to the main passage into the egg, such main being also provided with a perfect-fitting strong screw-valve and a long rod.

Near the bottom is a guide, the upper part of which traverses a very strong wooden frame in which is fixed the screw-worm, and having upon its top a small hand-wheel. When ready to charge, this valve is turned up and the cistern plug removed. When the egg

is full the cistern plug is reseated, and the screw-valve over the egg firmly fixed in its place.

The engine chosen for working the "egg" should have both a steam and air cylinder, worked with a direct stroke, and should be constructed to force acid through the delivery-pipe to the required height with ease and freedom.

The whole pumping-gear must be kept scrupulously clean and in good repair, and it is a wise measure of precaution to provide two "eggs" for each set of towers, so as to avoid, in case of a break-down, any stoppage of the process.

As the absorbing powers of concentrated sulphuric acid are known to become less, proportionately, with the increase in its temperature, the absolute necessity for effectually cooling that which runs from the Glover before passing it on to the Gay-Lussac tower need hardly be insisted upon.

A sufficiently long leaden worm pipe immersed in water, kept constantly cold, will answer all purposes.

The action which takes place in the denitrating column is extremely complicated.

Briefly stated, it may be said that the gases from the furnaces and the nitre-pots pass into and up the column at a temperature of from 900° to 1000° F., being met and traversed in their course by the fine down-pouring rain of acid proceeding from the two cisterns placed over its summit.

There thus simultaneously ensues a thorough denitration and concentration; the nitrous compounds given off by the acid from the Gay-Lussac tower and the steam resulting from the evaporation of the weak acid are both carried by the thoroughly cooled furnace gases into the chamber, the acid flowing into the bottom cistern being concentrated by the loss of its water to from 62° to 63° B.

The proper position naturally indicated for a Glover tower, therefore, is, as we have shown in our plan, as close a proximity to the burners as may be compatible with perfect safety from fire, since the hotter the gases, the greater will be the evaporation and the higher the degree of concentration of the acid flowing through it.

Some ten years ago Mr. Scheurer-Kestner pointed out that during the combustion of pyrites, there is formed in the furnace a large quantity of sulphuric anhydride which, being carried into the denitrator with the other gases, is presumably responsible, by its

corrosive action, for the rapid decomposition of the fire-bricks generally used for the base of the interior lining. Having continued his experiment up to recent times, the same distinguished author has published further and still more elaborate analyses, entirely confirmatory of his first discovery, and, as incontrovertible evidence, proves that the addition to a sulphuric-acid plant of a Glover tower, invariably results in an *augmentation of production amounting, according to its dimensions and the excellence of its construction, to from ten to twenty per cent., with no increase in the material employed.*

His operations were conducted in his own works, at Thann, with shelf-burners, consuming 5½ tons of pyrites—"fines" averaging forty-eight per cent. sulphur—daily. The whole of the acid produced in the chambers was passed through the Glover tower, where an evaporation of no less than 3½ tons of water was noted in every twenty-four hours. Starting with an accurate knowledge of the quantities contained in the chamber, tanks and various apparatus, the total daily production was accurately recorded during a period of sixteen days, at the end of which matters were so arranged as to be exactly in the same position as they were at the commencement of the experiment.

Of the 96 tons of 66° B. acid obtained, 15.152 tons, or 15.70 per cent., must have been formed in the tower. A second experiment, by what may be termed an indirect method, confirmed this result.

In this case the exact quantity of sulphuric acid condensed in the leaden chambers was accurately determined, with an absolute previous knowledge of what should be theoretically yielded from the amount of pyrites burned. The difference between this quantity, and that actually obtained, represented the excess formed or condensed in the Glover tower. Thus:

	Tons.
Sulphuric acid of 66° B. produced	48.300
Sulphuric acid of 66° B. condensed in the chamber	40.378
Difference representing the acid formed in the Glover tower.	7.922

Or 16.30 per cent

To these figures must be added the sulphuric acid which, passing with the gases through the tower in a state of vapor, was condensed in the connection-pipe. This being daily and exactly

measured during the course of each experiment, was found to represent from two, to two and a half per cent. of the whole product, the entire gain being thus brought up to the extraordinary total of about eighteen per cent. Mr. Scheurer-Kestner is probably one of the best manufacturing chemists in the world, and as a shrewd man of business, he supplements his theory by a very solid and practical final piece of evidence.

Using his own words, he says that before the Glover tower was erected in his works at Thann, his sets of chambers produced in each twenty-four hours six tons of oil of vitriol on the basis of 66° Beaumé. Ever since the tower has been adopted and brought to proper working order, the production has been increased to 7.280 tons. The difference, 7.280 — 6.000 = 1.280, in actual practical working, therefore, represents seventeen and a half per cent. of his total output.

Mr. Scheurer-Kestner attributes the formation of this sulphuric acid, outside the leaden chamber, to a double origin, about one-half being due to the anhydride produced during the combustion and dissolved by the descending current of liquid in the tower, and the other half being spontaneously formed by the action of the nitrous compounds on the ascending sulphurous acid.

COSTS OF PRODUCTION.

From what has preceded it is perfectly clear that the actual cost of sulphuric acid entirely depends upon three chief conditions:

First.—The price of sulphur.

Second.—The resources, adaptability and excellence of the working plant.

Third.—The chemical, mechanical and, generally, industrial skill of the working management.

It would, therefore, be obviously unfair to make any allowance for short-comings which have no right to exist, and it will be wise, in going into figures, to assume perfection in every detail.

A correct basis for calculation is furnished by what is commonly known as chamber acid—that is to say, the product daily formed in the chambers and subjected to no other concentration than that by the Glover tower. With proper care it may be made to average a gravity of say 52° Beaumé, and for the decomposition of average natural phosphates no greater strength than this is required.

If the entire product from the chambers were put through the Glover tower, the gravity could be run up to 60° or even 62° B. and the concentrated liquid could be easily reduced to any required strength by the addition of water, as shown by a table in a subsequent chapter.

The composition of pure H_2SO_4 is made up of 81.63 parts of sulphuric anhydride and 18.37 parts of water.

For every 100 pounds by weight it contains:

Hydrogen	2.041	pounds
Sulphur	32.653	"
Oxygen	66.306	"
Total	100	"

Hence the quantity of acid produced by 100 pounds of sulphur should be:

Sulphur	100.00	pounds
Hydrogen	6.20	"
Oxygen	199.80	"
Total H_2SO_4 equals	306	"

In other words, one pound of sulphur, when properly burned, theoretically yields 3.06 pounds of the monohydrate, with a specific gravity of 1.842 at 15° C. and 66° according to Beaumé's hydrometer. In practice, a regular average yield of about 2.95 pounds of 66° Beaumé, or even 4.50 pounds of 52° Beaumé, is considered an excellent result, and while the statements of manufacturers who claim to do better than this must be received with caution, it may nevertheless be laid down as an axiom that *from every pound of sulphur really burned, whether it be in the form of brimstone or of pyrites, the same amount of sulphurous-acid gas, and consequently of sulphuric acid, will, under all equal conditions, be produced.*

A reference to the annexed analytical table will show the proportion of sulphur contained in the pyrites now mined and used in this country.

TABLE OF THE AVERAGE COMPOSITION OF THE WORLD'S PYRITES.

	SULPHUR.	IRON.	COPPER.	ARSENIC.	ZINC.	LEAD.	GOLD.	SILVER.	CARBONATE LIME	SULPHATE LIME.	CARBONATE MAGNESIA.	SILICA.
	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.
Milan mine, New Hampshire, No. 1	46.00	40.00	3.75	traces	4.00	none	....	....	....	....	...	6.25
" " " 2	35.00	30.50	5.00	none	8.00	....	....	....	....	....	....	21.50
Davis mine, Massachusetts	49.27	45.30	1.47	traces	....	....	....	....	....	....	....	3.83
Elizabeth mine, Vermont	33.00	50.00	3.50	"	....	...	....	....	....	....	....	13.50
Saint Lawrence County, New York	38.00	34 00	3.00	"	....	....	....	....	....	....	....	25.00
Ulster County, New York	39.12	34.16	traces	"	...	....	....	....	....	....	....	26.69
Arminius mine, Virginia	46.00	44.50	1.00	"	....	....	....	variable	....	....	....	7.40
Gaston County, North Carolina	44.00	36.00	traces	"	....	....	....	none	....	....	....	20.00
Paulding County, Georgia	41.00	37.00	4.00	"	....	....	....	"	....	....	....	18.00
Ducktown, Tennessee	35.00	40.00	5.00	none	....	....	....	"	8.00	....	....	12.00
Capleton, Canada	40.21	35.20	3.00	traces	....	....	variable	variable	...	....	....	19.43
Rio Tinto mines, Spain	48.50	40.92	2.50	0.33	0.22	1.52	"	"	0.90	....	....	3.46
Tharsis " "	49.90	42.55	3.10	0.47	0.35	0.93	"	"	0.37	0.50	....	2.20
San Domingo, Portugal	49.07	44.28	3.25	0.38	....	....	"	"	0.68	....	0.25	2.59
Swedish mines, average	38.05	42.80	1.50	none	....	....	none	traces	5.09	....	....	12.56
Norwegian " "	46.15	44.20	2.10	traces	1.20	....	....	....	2.50	....	....	3.65
French " "	46.60	39.70	none	"	....	....	....	....	0.20	....	....	13.50
German " "	45.60	38.52	....	0.95	6.00	0.74	....	....	....	...	....	8.19
Belgian " "	42.80	36.70	....	0.20	0.40	0.92	....	....	4.75	0.65	1.05	12.47
English " "	34.34	32.20	0 80	0.91	1.32	0.40	....	....	....	....	....	30.03
Irish " "	47.41	41.78	1.93	2.11	2.00	....	....	....	....	....	....	4.77

From these figures it will appear that the average may be safely taken at forty-six per cent. of sulphur, and of this amount, a varied experience has demonstrated that at least six per cent. are generally unavailable and should therefore be regarded as loss.

The prices of raw material given in the following table are intended to cover all costs of delivery to works in readily accessible shipping ports, and are based, not upon the high values now prevailing for brimstone and communicated to it by speculation, but upon the average prices which have prevailed during the past five years.

In the pyrites estimate, considerable additions have been made to the items of nitre and labor, and it has been considered wise in both cases to write off the whole value represented by the works in ten years, experience of this system in practice having proved highly satisfactory.

Despite sundry drawbacks the balance of advantage is unequivocally shown to be on the side of the pyrites, even when utilized at centres so far distant from the sources of production as to entail a very heavy freight.

TABLE OF COMPARISON SHOWING THE ACTUAL COST OF PRODUCING ONE TON OF 52° BEAUMÉ SULPHURIC ACID FROM BRIMSTONE AND PYRITES IN ACCESSIBLE SHIPPING PORTS.

Brimstone (short tons).

1 ton of brimstone (98 per cent. S.) thirds, at $21	$21.00
50 lbs. of nitrate of soda, at 2½ cents per lb	1.25
500 lbs. coals, at, say, $4 per ton	1.00
Workmen's wages	2.25
Superintendence and management	2.00
General jobbing repairs	50
Interest on capital of $75,000 at 10 % per year, the works being calculated to produce 20 tons daily and to last for ten years	4.60
Total	$32.60
Product equals 4¼ tons of 52° B. Cost per ton	$7.65

Pyrites (short tons).

2½ tons of iron pyrites at 46 per cent. sulphur, at 12 cents per unit and per ton	$13.80
60 lbs. nitrate of soda, at 2½ cents per lb	1.50
500 lbs. of coals, at, say, $4 per ton	1.00
Workmen's wages	3.00

Superintendence and management	2.00
General jobbing repairs	60
Interest on capital, same terms as above	4.60
Total	$26.50
Product equals 4½ tons of 50° B. Cost per ton	$5.90

We have already hinted at the feasibility of manufacturing the acid in the vicinity of the pyrites mines, but have not forgotten to add that its practicability must be established by clearly demonstrating that the cost of carrying phosphates or 66° B. acid is less than the freights now paid upon the pyrites ore.

The problem deserves to be inquired into by capitalists, since its favorable solution would still more reduce costs, as follows:

COST OF ACID PRODUCTION AT THE MINES.

2½ tons of iron pyrites, containing 46 per cent. sulphur, at a maximum of 5 cents per unit delivered at the works.	$5.75
Other charges, same as given in preceding table	12.70
Total cost of 4½ tons 50° B. acid	$18.45
Cost per ton	$4.10

To put it plainly, the manufacturer at the mines would be working upon sulphur which, on an exactly equivalent chemical basis of calculation, would cost him $15.25 less per ton than the price paid for brimstone by his competitors.

CHAPTER VII.

THE MANUFACTURE OF SUPERPHOSPHATE, PHOSPHORIC ACID, AND "HIGH-GRADE SUPERS."

THE process of superphosphate manufacture from mineral phosphates is not very generally understood, and while neither very complicated nor difficult, requires a certain amount of chemical knowledge and experience which the majority of those concerned in it do not possess. Hence it follows that no article in the market is more variable, both in its physical condition and chemical composition.

Nor can this remain a source of surprise when we remember that each manufacturer adopts some peculiar system of his own, and that no two fertilizer factories bear any resemblance to each other.

We have seen that raw phosphates, whether of animal or mineral origin, are made up of three molecules or parts of lime (CaO) combined with one molecule or part of phosphoric anhydride (P_2O_5). The words acid phosphate, superphosphate, water-soluble phosphate, are all used to describe a product obtained by treating these raw phosphatic materials with a sufficient proportion of sulphuric acid to transform two out of their three molecules of lime into sulphate of lime or gypsum ($CaSO_4$).

To the lay reader, the chemistry of the mixture will be more readily understood if we briefly explain, that when a piece of pure phosphorus is burnt in contact with dry air it gives off vapors, every two atoms of which combine with five atoms of atmospheric oxygen to form a snow-white powder. This powder is the phosphoric anhydride above alluded to, and it has a molecular weight of 142. Its chief characteristic is its attraction for water, and if left temporarily exposed to the air it rapidly deliquesces.

In this moist state it is found to have combined with water in the molecular ratio of 1 : 3, and its composition has become

Phosphoric anhydride (P_2O_5).....	1 mol.	= 142 by weight.
Water (H_2O).....	3 mols.	= 54 "
Or, Phosphoric acid (H_3PO_4).....	2 mols.	= 196 "

In other words, every 100 parts of it contain

Phosphoric anhydride (P_2O_5)	72.45
Water (H_2O)	27.55
	100

And it may be regarded as typical of the tribasic combination in which the anhydride is always encountered in nature.

It has the faculty of exchanging one, two, or all three of its water-molecules, for molecules of various bases, and thus we are quite familiar with it as

$CaO(H_2O)_2P_2O_5$, or *acid phosphate of lime*, in which it has taken one molecule of lime in place of one molecule of water;

$(CaO)_2H_2O\ P_2O_5$, or *neutral phosphate of lime*, in which it has taken two molecules of lime in place of two molecules of water; and

$(CaO)_3P_2O_5$, or *tribasic phosphate of lime*, in which all the water-molecules have been displaced by lime.

The first of these compounds is soluble in water.

The second insoluble in water but soluble in neutral citrate of ammonia.

The third is only soluble in strong acids.

When quite pure, every 100 parts of each of them is made up of—

	Acid Phosphate of Lime.	Neutral Phosphate of Lime.	Tribasic Phosphate of Lime.
Phosphoric anhydride (P_2O_5)	60.68	52.20	45.81
Lime (CaO)	23.93	41 .18	54.19
Water (H_2O)	15.39	6.62	.....
	100	100	100

The tricalcic or last of these compounds is the phosphate of lime which occurs in the deposits we have been engaged in considering, and the problem of making it soluble in water or in neutral citrate of ammonia has been worked out by chemists on the following basis:

Sulphuric acid is known to be more energetic in its action at ordinary temperatures than any other acid used in industry. It therefore has the power of displacing all other acids from their salts and of taking their bases to itself to form sulphates.

The acids chiefly present in natural phosphates are phosphoric, carbonic, fluoric and silicic, and these, when brought into contact

with diluted sulphuric acid, are all dislodged. The bases become sulphates. The phosphoric anhydride combines with water and remains in the mass as free phosphoric acid, while the carbonic, fluoric, and part of the silicic acids, go off as vapor, the two latter generally combined in the very poisonous form of silicon tetrafluoride. In the manufacture of fertilizers, however, as at present carried out, the object is not to produce free phosphoric acid, but "*acid phosphate*," since, as we have already seen, this latter salt is quite soluble in water, and therefore can fulfil all the conditions that are deemed by some authorities to be essential in a plant food. It hence follows that the substitution of the bases must not be complete, but must be only carried to a sufficient point to displace all foreign acids, and to saturate two out of the three molecules of the lime combined with phosphoric anhydride.

Lest this proposition should appear too complicated, we may endeavor to make it more clear by an example, in which we shall assume that we are called upon to deal with a Florida phosphate, the composition of which has been determined by chemical analysis to be as follows:

Moisture and organic matter.....	3.90
Tribasic phosphate of lime.....	79.40 (equal to 36.42 P_2O_5)
Carbonate of lime	5.48
Phosphates of iron and alumina...	3.00 (equal to about 1.50 P_2O_5)
Carbonate of magnesia	0.72
Sulphate and fluoride of lime.....	3.20
Sandy matters, silicates, etc	4.30
	100

The sulphuric acid known as "*chamber acid*" when measured with Beaumé's hydrometer at a temperature of 60° F., contains the following percentages of sulphuric anhydride (SO_3) and pure monohydrate (H_2SO_4):

Degrees Beaumé at 60° F.	*Percentage of SO_3 (Anhydride)*	*Percentage of H_2SO_4 (Monohydrate).*
48.....	48.70	59.63
49.....	49.80	61.00
50.....	51.00	62.47
51.....	52.20	63.94
52.....	53.50	65.53
53.....	54.90	67.30
54.....	56.00	68.60
55.....	57.10	69.94

With the analysis and this table before us, we may proceed to find out in what proportions the powder and the liquid must be brought together to transform the insoluble phosphates into a water or citrate soluble form, and we acquire this knowledge by resorting to an equation, which we will endeavor, as an example, to produce in its simplest expression :

Molecular Weights.

310		196				
$Ca_3P_2O_8$	+	$2H_2SO_4$	=	$2CaSO_4$	+	$CaH_4P_2O_8$
1 molecule of tribasic phosphate of lime	+	2 molecules of monohydrate sulphuric acid	=	2 molecules gypsum	+	1 molecule of "super" or acid-calcic phosphate.

Molecular Weights.

100		98						
$CaCO_3$	+	H_2SO_4	=	$CaSO_4$	+	CO_2	+	H_2O
1 molecule of carbonate of lime	+	1 molecule of monohydrate sulphuric acid.	=	1 molecule of gypsum	+	1 molecule of carbonic-acid gas	+	1 molecule of water or steam.

Molecular Weights.

245		294				
$(AlPO_4)_2$	+	$3H_2SO_4$	=	$Al_2(SO_4)_3$	+	$(H_3PO_4)_2$
1 molecule of phosphate of alumina	+	3 molecules of monohydrate sulphuric acid	=	1 molecule of sulphate of alumina	+	2 molecules phosphoric acid.

Molecular Weights.

302		294				
$(FePO_4)_2$	+	$3H_2SO_4$	=	$Fe_2(SO_4)_3$	+	$(H_3PO_4)_2$
1 molecule of phosphate of iron	+	3 molecules of monohydrate sulphuric acid	=	1 molecule of ferric sulphate	+	2 molecules phosphoric acid.

Molecular Weights.

84		98						
$MgCO_3$	+	H_2SO_4	=	$MgSO_4$	+	CO_2	+	H_2O
1 molecule carbonate of magnesia	+	1 molecule of monohydrate sulphuric acid	=	1 molecule sulphate of magnesia	+	1 molecule carbonic-acid gas	+	1 molecule water (or steam).

Molecular Weights.

78		98				
CaF_2	+	H_2SO_4	=	$CaSO_4$	+	2HF
1 molecule of calcium fluoride	+	1 molecule of monohydrate sulphuric acid	=	1 molecule of gypsum	+	2 molecules of hydrofluoric acid.

If *three hundred and ten parts of tribasic phosphate of lime* require *one hundred and ninety-six parts of the pure monohydrate of sulphuric anhydride* (H_2SO_4) for its transformation into monocalcic or acid-phosphate, it follows that 1 part will require .632 *parts* of the acid.

Assuming the chamber acid we are called upon to use to be of 50° B. strength, we refer to our table and find that it contains 62.47 per cent. of pure H_2SO_4. The quantity of it to be taken as an equivalent of .632 parts of the latter, therefore, is found by the equation: $62.47 : 100 : : 0.632\,x = 1.012$ *parts*, and this is the method of calculation we must observe for all the bodies *shown to exist in our sample of phosphate.*

TABLE SHOWING THE QUANTITY OF CHAMBER SULPHURIC ACID OF VARIOUS STRENGTHS —EXPRESSED IN POUNDS—REQUIRED IN THE MANUFACTURE OF SUPERPHOSPHATE FROM NATURAL PHOSPHATES IN ORDER TO PRODUCE ACID-PHOSPHATE.

Every pound of the following substances requires—	Acid at 48° B. Pounds.	Acid at 49° B. Pounds.	Acid at 50° B. Pounds.	Acid at 51° B. Pounds	Acid at 52° B. Pounds.	Acid at 53° B. Pounds.	Acid at 54° B. Pounds.	Acid at 55° B. Pounds.
Tribasic phosphate of lime	1.060	1.036	1.012	.988	.965	.940	.921	.903
Carbonate of lime.....	1.640	1.605	1.565	1.535	1.495	1.456	1.428	1.411
Phosphate of alumina.....	2.025	2.008	1.930	1.884	1.839	1.790	1.756	1.721
Phosphate of iron.....	1.630	1.595	1.558	1.521	1.485	1.446	1.420	1.390
Carbonate of magnesia...	1.949	1.905	1.860	1.815	1.775	1.726	1.690	1.660
Fluoride of lime.....	2.006	2.059	2.010	1.962	1.916	1.866	1.830	1.794

With a proper application of the data thus furnished there should be no difficulty in dealing with any phosphatic material of which the composition is accurately known, and it is only necessary, in proof of this, to give one more illustration.

Returning to the phosphate we have already used, but assum-

ing for the sake of variety that our chamber acid is of 52° B. strength instead of 50° B., we shall find that

79.40 lbs.	phosphate lime	× .965 =	76.62 lbs.
5.48 "	carbonate "	× 1.495 =	8.19 "
3.00 "	phosphates of iron and alumina combined	× 1.839 =	5.52 "
0.72 "	carbonate of magnesia	× 1.775 =	1.28 "
3.20 "	fluoride of calcium	× 1.916 =	6.13 "
	The total quantity of 52° B. acid required for every 100 lbs. of raw material, in order to bring the insoluble phosphates into a soluble form, is therefore ...		97.74 "

It would thus appear to the unobserving, that a mixture of one ton each of the raw materials produces, after allowing for certain losses in the fabrication—such as evaporation—about two tons of fertilizer, and that we have gone to unnecessary trouble to demonstrate a very simple fact. Such "rule-of-thumb" reasoning is no doubt responsible for the many bad "supers" we meet with in the trade, and the present is therefore the right time to ask what kind of a fertilizer has been thus prepared. As a matter of absolute fact, no question is so little understood by the majority of those who should be able to answer it, and yet no other is of so much importance.

We have been taught by chemistry that certain qualities are essential in a fertilizer in order that it may produce its results with rapidity and economy. Without a sufficient knowledge of the reactions involved, how can the possession of these qualities be invariably assured and conscientiously guaranteed?

Let us therefore examine a little more closely into the nature of this very complicated body.

As revealed to us in our own practice and by the experience of other chemists, there can be no reasonable doubt that the tricalcic phosphates of mineral origin, when treated with sulphuric acid, become partially or wholly changed into three distinct forms:

1. Free phosphoric acid soluble in water.
2. Acid phosphate of lime soluble in water.
3. Neutral phosphate of lime insoluble in water, but readily soluble in neutral citrate of ammonia.

There can also be no doubt that the nature and extent of this change, as well as the physical condition of the mass resulting from the mixture, will depend entirely upon two factors:

A. The skill and intelligence of the practical operator.

B. The nature and composition of the phosphate to be handled.

Assuming that *A* leaves nothing to be desired, the bulk of our average raw phosphates still offers two difficulties of considerable magnitude. If they are treated with the theoretical amount of acid, as in our example, they may yield a wet, pasty mass or mud which can only be dried with difficulty, and which therefore remains long unmarketable. If, on the other hand, something less than the theoretical quantity of acid be taken, a certain proportion of the substance remains unattacked and therefore becomes neither "water" nor "citrate" soluble. This is because there is in their composition, either a lack of some needed, or an excess of some objectionable constituent, and we are hence led to quite naturally inquire, what we are to regard as a defective phosphate.

The result of prolonged investigations pursued under many and varying conditions has proved to us, that next to an insufficiency of the phosphoric acid itself, a lack or insufficiency of *carbonate of lime* is the most serious defect. This defect is augmented in the presence of *iron and alumina* in any form.

In Europe, and especially in England, high-grade phosphates have great commercial value, but they lose part of it when the oxides of iron and alumina, taken together, exceed three per cent.

This is because the market price of the English manufactured fertilizer is made dependent upon its percentage of water-soluble phosphoric acid, and because, even when all other conditions are favorable, the presence of iron and alumina gradually causes "water"-soluble to revert into "citrate"-soluble phosphates when kept for a short time ready made in the factory. When an acid of greater average strength than 50° B. is used for the attack on the phosphate—and stronger acids are frequently necessary—free phosphoric acid is at first almost exclusively produced as a result of the reaction. After a little time, when the temperature is at its maximum, this free phosphoric acid commences to react upon the undecomposed material, and first of all upon any iron and alumina that may be present. Bodies insoluble in water result from this reaction, and hence the English fertilizer makers studiously avoid all mineral phosphates containing more than the stated maximum.

In this country we are not handicapped by any such foolish prejudices. Our farmers are hard-headed and practical and have no marked preference for *water-soluble* phosphoric acid. They have been taught by theory and have proved by their own field practice, that citrate-soluble phosphates are readily transformed into plant food by the elements in the soil. This being the case,

all they ask of us is the maximum of "*available phosphoric acid*" in a fine, dry and merchantable condition, and this we can give them without difficulty and without regard to a few units more or less of oxides of iron and alumina, by carefully regulating the percentage of carbonate of lime in our raw product. When circumstances allow of this regulation, through the mixture of a phosphate containing much carbonate, with another containing little or none—as for instance, the blending of Canadian apatite with Belgian cretaceous phosphates—we personally prefer that course, but where such facilities are wanting, we invariably resort to the addition of finely powdered chalk, or any other cheap and available source of the carbonate.

This method of facilitating spontaneous drying was suggested by us to a few manufacturers some years ago, and has been deprecated and denounced as far too costly for general use. Those who denounced it, however, have not yet made known a cheaper or more practical plan, for the one which they proposed, of effecting the drying by the application of external heat in ovens or on hot floors, has invariably proved disastrous. How could it in fact do otherwise, when we know that monocalcic or water-soluble phosphate of lime cannot exist in any other than the hydrated state?

In making our proposal, we had borne in mind that this hydrated state can only be preserved by spontaneous drying, and we had experimented enough to know that this drying can only be easily effected as we have described. We consequently can see no more valid reason to-day than we could ten years ago, why, under proper restrictions, the carbonate should not be used.

The difficulties of a manufacturer only commence when he is called upon to use a refractory raw material, and it is only under such circumstances that he finds scope to develop the fertility of his resources. If our mineral phosphates were not of ever-varying composition, a knowledge of chemistry would not be so essential to their treatment, but as the case stands we are helpless without the assistance of the analyst. In his absence the manufacturer gropes blindly in the dark, for he knows not what elements he is mixing together and can predict nothing concerning the nature of the compound that will result from their reactions on each other.

Figures, like actions, are more eloquent than words, and as our assertions are made on the strength of our own work, we will close this part of our argument by giving some examples that should carry conviction.

The following experiments were made with Florida phosphate containing as high as eight per cent. of iron and alumina. After having been tried in several factories and pronounced worthless for the purpose, they were finally made into superphosphates of exceptionally good quality.

The composition of the material was:

Phosphate of lime	81.10 (equal to 37.20 P_2O_5)
Carbonate of lime	3.70
Oxides of iron and alumina (combined)	7.90
Moisture, insoluble, and undetermined	7.30
	100

One hundred pounds of it were treated with 94 pounds of 55° B. chamber acid, and one hour after the "super" had dropped into the "den" a sample was drawn from various points, mixed, analyzed and found to contain:

Total phosphoric anhydride soluble in hydrochloric acid	20.01
Of which there was found to be	
Water-soluble phosphoric anhydride	15.90
Citrate-soluble " "	16.30

At the end of ten days this "super" was still in the "den" and in a very wet and unmanageable condition. Sampling and analyses were repeated, and it was now found to contain:

Total phosphoric anhydride soluble in hydrochloric acid	19.96
Of which there was found to be	
Water-soluble phosphoric anhydride	15.10
Citrate-soluble " "	17.01

Another batch was made with the same lot of phosphate after adding to it eight per cent. by weight of very finely powdered chalk. Upon analyses before treatment with acid it was now shown to contain:

Phosphate of lime	75.03 (equal to 34.40 P_2O_5)
Carbonate of lime	10.72
Oxides of iron and alumina (combined)	7.27
Moisture, insoluble, and undetermined	6.98
	100

One hundred pounds were passed through a 70-mesh screen and then worked up with 92 pounds of 55° B. chamber acid as before, and dropped into the "den." At the end of an hour, when the sample

was drawn as in the last experiment, it had already commenced to "set," and the result of the analysis was :

Total phosphoric anhydride soluble in hydrochloric acid....	18.97
Of which there was found to be	
Water-soluble phosphoric adhydride.....	16.30
Citrate-soluble " "	18.10

At the end of thirty-six hours after mixing, it was dry enough to be dug out of the "den" and was in a very porous and friable state, the analysis at this time showing it to contain :

Total phosphoric anhydride soluble in hydrochloric acid....	19.19
Of which there was found to be	
Water-soluble phosphoric anhydride.....	16.17
Citrate-soluble " "	18.53

The increase in the last figure was due to decrease in moisture.

In order to test the question of the advisability or otherwise of calcining the phosphates in preference to drying them by means of hot air, a third experiment was performed at the same works. Before treatment with acid the finely comminuted material (70-mesh) was analyzed with the following result :

Phosphate of lime.....	77.18 (equal to 35.40 P_2O_5)
Carbonate of lime.....	3.64
Quick-lime	4.65
Oxides of alumina and iron (combined)	7.53
Moisture, insoluble, and undetermined	7.00
	100

After being worked up with 92 pounds of 55° B. sulphuric acid it was dropped into the "den" as usual, and sampled and analyzed at the end of an hour, as in the other cases. *It was still quite wet* and yielded :

Total phosphoric anhydride soluble in hydrochloric acid....	18.72
Of which there was found to be	
Water-soluble phosphoric anhydride.....	15.54
Citrate-soluble " "	16.79

It was removed from the "den" on the eighth day after its manufacture, in *a very damp and unsatisfactory condition*, quite unfit to pass through the pulverizer or to be put into bags. It yielded on analysis :

Total phosphoric anhydride soluble in hydrochloric acid.. .	18.93
Of which there was found to be	
Water-soluble phosphoric anhydride	15.03
Citrate-soluble " "	17.01

Unless our conclusions are ill-founded in every particular, these figures and details confirm the position we have assumed.

In the first place, they prove that raw mineral phosphates containing a fair proportion of carbonate of lime may carry a high percentage of iron and alumina and yet yield a perfectly dry and pulverulent product, in which nearly all the phosphoric acid is in a readily soluble or available form. As a necessary consequence, while this amount of carbonate certainly calls for an increased outlay of sulphuric acid and thereby adds somewhat to the cost of manufacture, it is, nevertheless, in the end a source of the truest kind of economy and profit.

In the second place, they prove what we have never ceased to claim, that to calcine Florida phosphates would be both unscientific and harmful, and that whereas the production of a dry and porous "super" always follows the use of carbonate, the presence of free lime always retards the drying action.

In the third place, they prove the necessity for complete chemical analysis of the raw material, and demonstrate the utter worthlessness of analytical reports which merely give the percentage of total phosphoric acid, calculated to its equivalent of tricalcic or "bone" phosphate. What kind of iron and steel would be produced, if those concerned in that industry were content to know the mere percentage of metallic iron contained in a sample of iron ore?

Turning now from the purely chemical, to that side of the industry which calls for mechanical details, we come first to the operation of grinding the raw phosphate, and we may be allowed to say that this is a matter for the most serious attention.

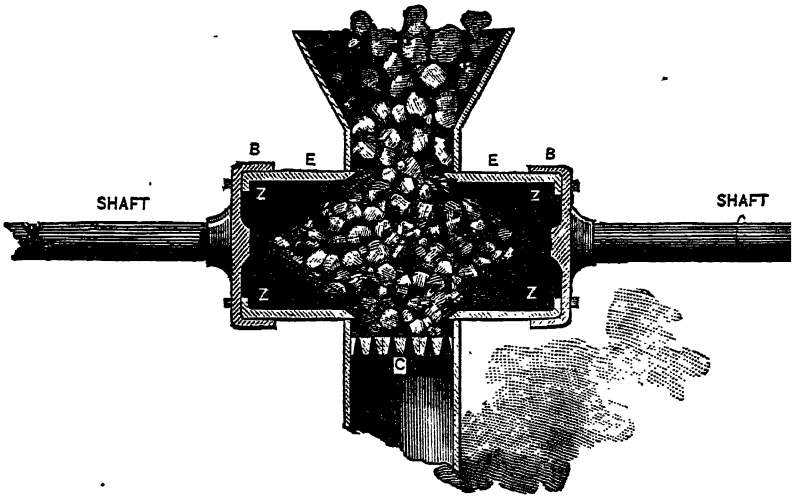
A growing recognition of the necessity for extremely fine grinding is one of the most satisfactory results of scientific teachings, and we are glad to see that progressive manufacturers now admit it to be the only means of attaining high dissolving efficiency.

In proportion to the natural hardness of the phosphate rock this necessity for fine separation of the particles increases, and it has been the experience, with Canadian apatites for example, that unless the material is so disintegrated as to pass freely through a 70 or even an 80 mesh screen, it is only very slowly and incompletely acted upon by 50° B. sulphuric acid.

Several popular methods of grinding now give great satisfaction on the industrial scale, and of these we may mention the plants which comprise—

First.—A Blake stone-crusher for reducing the lumps to the size of small marbles, attached to a set of French burr mill-stones fitted with revolving screens up to 90 or 100 mesh.

Second.—The Sturtevant mill and crusher, which is composed of two cylindrical heads, or cups, arranged upon the opposite sides of a case, into which they slightly project, facing each other, and are made to revolve in opposite directions. The rock, being conveyed to the interior of the case through the opening at the top, is re-



THE STURTEVANT MILL IN CROSS-SECTION.

tained and prevented from dropping below the revolving heads or cups by a cast-iron screen, and entering, as it must, the heads or cups in revolution, is immediately thrown out again from each cup, in opposite directions, with such tremendous force that the rock from one cup in the collision with the rock thrown oppositely from the other cup is crushed and pulverized, and the grinding, which otherwise would be upon the mill, is transferred to the material, which is at once reduced to powder.

The mill is composed of four elementary parts—a case, two hollow heads or cups, and a screen.

The principle of its construction is shown in the above cross-section of its elementary parts.

B B represent the two opposite heads or cups of the mill holding the two bushings E E, which slightly project into the case. At Z Z, the stone hollow cones are shown (which form themselves in each head by the packing of the rocks being ground after the machine has been run a few moments). The hopper is filled with rocks, which drop into the case of the machine between the two heads. In a few moments after the mill has started the two stone hollow cones Z Z form themselves and become as hard as the rock. When these hollow cones have formed, the centrifugal force given by their revolution will hurl out of the hollow cones in the general directions indicated by the arrows all the rocks that are forced into them. The iron confining-screen C is of very small diameter, and an important object is accomplished by this arrangement. The ground rock is let out of the screen at once.

We have found it advisable to attach a set of rock-emery stones to this mill for grinding the fine tailings, which amount to about thirty per cent. In this way the average milled product of 70-mesh may be fairly taken as about three tons per hour.

Third.—The Griffin mill, which is of the class known as a roller and die mill, in which the material is reduced by being crushed by a roll running within and against the inner surface of a ring or die.

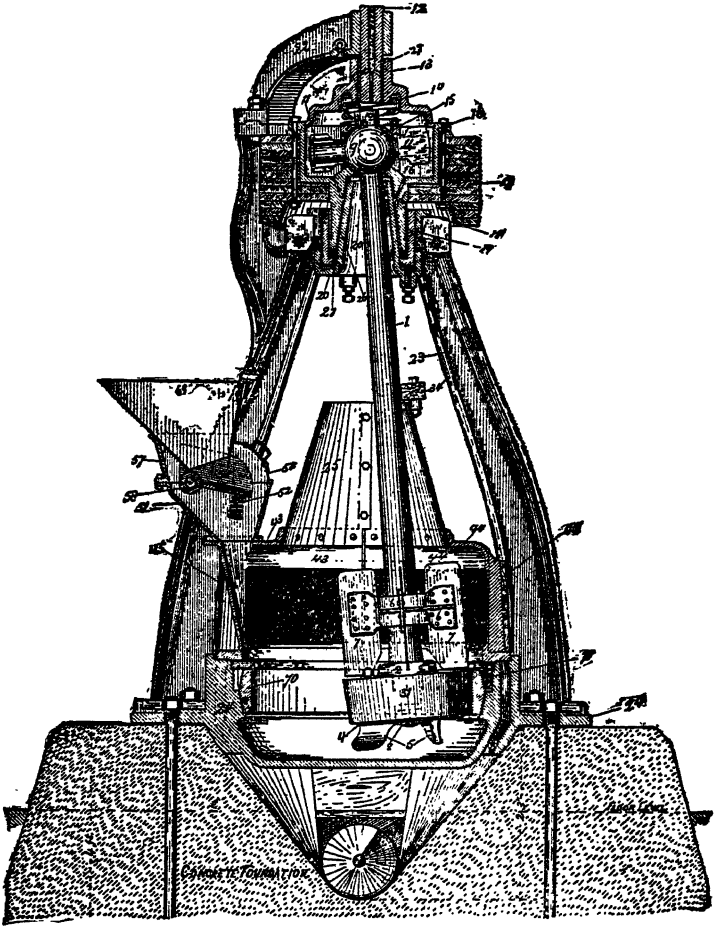
It is a substantial mill and receives its power by a pulley running horizontally. From this pulley is suspended the roller-shaft, by means of a universal joint, and to the lower extremity of this shaft is rigidly secured the crushing-roll, which is thus free to swing in any direction within the case.

The illustration on the next page shows that the case consists of the base or pan (24) containing the ring or die (70), against which works the roll (31) and upon the inner vertical surface of which the crushing is done.

This pan or base has a number of openings through it downward outside of the ring or die which lead into a pit or receptacle below. Upon this base is secured the screen-frame (44), which is surrounded with a sheet-iron cover (45) and to the top of which is fastened a conical shield (25) open at the apex, through which the roll-shaft works.

To this cone is attached the feeder-arm (34) by means of which the automatic feeder is operated. The crushing-roll is attached to the end of the lower or roll-shaft (1), and just above the roll is the fan (7). On the under side of the roll are shown shoes or ploughs

(5), varying in shape according to the nature of the work to be done. The pulley (17) revolves upon the tapered and adjustable bearing-stud (20), which is in turn supported by the frame composed of the standards (23). Two of these standards (23a) are extended above



SECTIONAL VIEW OF THE GRIFFIN MILL.

the pulley to carry the arms (22) in which is secured the hollow journal pin (12). Within the pulley is the universal joint from which the roll-shaft (1) is suspended. This joint is composed of the ball or sphere (9) with trunnions attached thereto. These trunnions work in half-boxes (11) which slide up and down in re-

cesses in the pulley-head casting (16). The joint in the pulley is inclosed by means of the cover (13), thus keeping the working parts away from all dust and grit, and lubricating oil is supplied for all parts needing it through the hollow pin (12).

When the mill is started, the pulley and the roller-shaft revolve together, the roller hanging free in the centre of the ring, when, the shaft being pushed outward, the roll on its lower end comes in contact with the ring or die and immediately begins to travel around on the latter's inner surface, pressing against it with a force sufficient to effectually pulverize anything that comes in its way. The material to be reduced is fed into the mill in sufficient quantity to fill the pan as high as the shoes or ploughs on the lower side of the roll. The ploughs then stir it up and throw it against the ring, so that it is acted upon by the roll, and when fairly in operation, the whole body of loose material whirls around rapidly within the pan and up against the screens, through which all that is sufficiently fine passes at once, the coarser portion falling down to be acted upon again.

The universal joint, by which the roll-shaft is connected with the pulley, allows perfect freedom of movement to the roll so that it can easily pass over obstructions of any kind. Pieces of iron or steel, such as are usually found in all rock to be ground, do no damage to the mill.

In dry grinding the fine material that passes through the screens falls downward through the openings outside of the ring into the receptacle underneath, from which it is carried by a conveyer provided for that purpose.

The fan attached to the shaft above the roll draws a small quantity of air in at the top of the cone, forcing it through the screens and out into the discharge, thus effectually keeping all dust within the mill.

It is stated of this mill that four tons of South Carolina phosphate rock (seventy-five per cent. of which would pass through a 70-mesh screen) may be ground and passed through the screens in an hour.

Fourth.—The Frisbee-Lucop phosphate mill, which is built of steel and weighs about three tons. It is driven by belt, develops a speed of 300 revolutions under full feed, requires 18 horse-power, and is said to be capable of grinding 15 tons of phosphate rock to a fineness of No. 150 mesh, per day of ten hours.

The pulverization of the material is effected by heavy cylindrical rollers which are caused to revolve upon the inner surface

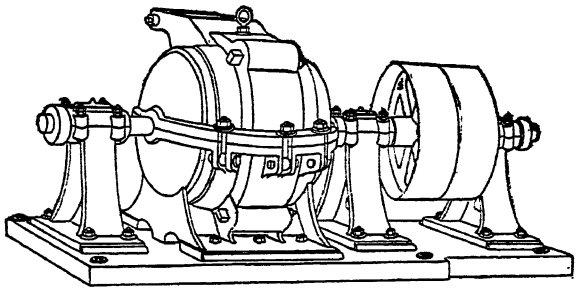
of a steel ring, against which they exert a pressure of some 2000 pounds per square inch. The effect of this force is augmented by a differential grinding motion imparted by the drivers.

As fast as it is produced, the pulverized is separated from the coarse material, by gravity, being drawn from the mill through pipes connected with the top of the casing by an exhaust-fan, and carried to settling bins or chambers.

Five different varieties of steel, each having special characteristics suited to the requirement, are used for the interior or working parts of the machine. The wearing parts, being few in number and simple in shape, are readily replaced when worn.

The construction of the mill will be easily understood from the following transverse vertical section through its centre.

The shaft S is of hammered steel, 39 inches between bearings,



THE FRISBEE-LUCOP PHOSPHATE MILL.

which are $3\frac{1}{4}$ inches by 10 inches long. Pulleys are double-arm, fast and loose, 28 inches in diameter by 8-inch face.

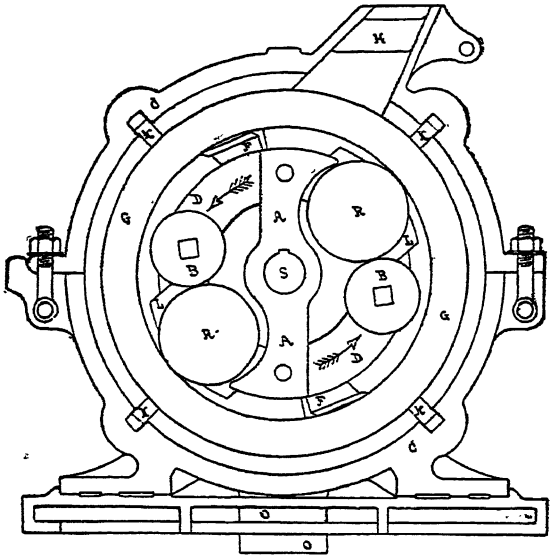
To the shaft is keyed the driving-arm A A previously forced on. This is a solid casting $6\frac{1}{16}$ inches thick through the ends and $9\frac{1}{2}$ inches through the flanges or hub. The rear ends of the arm are made concave to receive the rolls when the mill is at rest. Upon both sides of the arm are fastened the discs D D, annular plates fitting around the flanges of the arm and firmly secured to it by two disc-bolts $1\frac{3}{8}$ inches in diameter.

Between the discs are placed the drivers B B, two in number, rigidly bolted to the discs by the two driver-bolts, $1\frac{1}{2}$ inches square. The drivers are cylindrical, $6\frac{1}{16}$ inches long by 6 inches diameter, made of cast-steel or forged iron, and weigh 45 pounds each. When worn by contact with the rolls they may be turned a quarter circumference on the bolt. This may be repeated until the four sides are worn.

There are two rolls, R R, of chrome steel, 8 inches in diameter by 6-inch face, weighing about 80 pounds each. They are held free in position by the discs between their drivers and the rear ends of the arm.

The fan-blades F F, four in number, are of steel or wrought-iron and are firmly fastened on each disc exteriorly by the disc-bolt and dowel-pin, and distribute the material to be pulverized into the path of the rolls.

Four liners, L L, or thin steel plates are placed between the



VIEW OF TRANSVERSE VERTICAL SECTION OF FRISBEE-LUCOP PHOSPHATE MILL.

ends of the rolls and the discs (cut to receive them) and take the wear off the ends of the rolls.

The revolving parts of the mill centred within the ring have all a uniform motion with the shaft, but the rolls have an independent motion around their axes. The ring G G is of rolled steel, 6 inches face and 3 inches in thickness, held in position by wedge-keys K K to the casing of the mill C C. Exterior to the "centre" are two small circulating fans (wrought blades in a cast hub), the purpose of which is to keep the pulverized material in circulation so that it may be readily withdrawn by the exhaust-fan which carries the product of the mill to the settling-bins.

The casing of the mill is of cast-iron, divided horizontally.

The upper and lower halves are held together by hinged bolts in slots cut in the flange of each section. The upper half is hinged to the lower at one side and is easily raised so as to give free access to the interior of the mill for examination and the replacing of worn parts. The casing and the three pedestal bearings for the shaft are seated upon a heavy bed-plate as indicated in the illustrations. Being a balanced machine it does not require elaborate or expensive foundations.

The difficulty of estimating the exact cost of grinding phosphates to a fineness of 70 or 80 mesh, either by the methods we have thus described or any others now in use and perhaps equally good, is naturally very considerable, since so much must, perforce, depend upon the nature of the material itself. We have seen it variously estimated at from 50 cents to $2 per ton, and have even met those who claim to be able to do the needful work for less than the first figure. As a matter of sober fact, however, we have found that in practice, when breakages, repairs and general wear and tear are taken into account, $1.50 per ton is more like the proper figure, and we therefore usually adopt it as a fair basis for calculations.

The operation of grinding having been satisfactorily performed, the phosphate is submitted to *complete analysis* and, its chemical composition being thus known, is finally conveyed to the mixer.

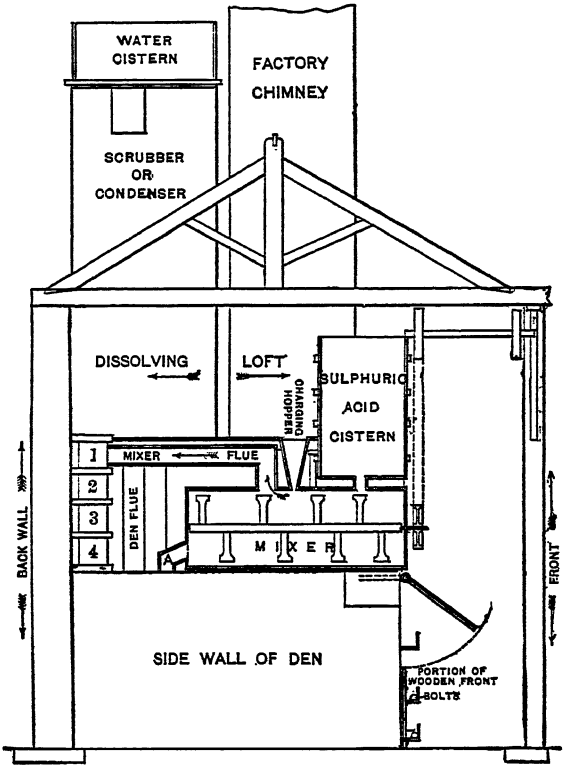
The mixing together of the raw materials in the proportions determined by proper computation is performed in a commodious shed, of which the annexed drawing will convey the necessary understanding. It must be near to the sulphuric-acid chambers, and directly connected with a high shaft or chimney and a condensing apparatus or scrubber; the latter for absorbing the noxious fumes set free by the decomposing mass.

A strong brickwork shell with a good foundation is built in the centre of the shed. This shell is divided off into from six to twelve chambers or "dens" some 15 feet square and 20 feet high, each of which must communicate, by means of a good-sized flue, with the scrubber and factory chimney.

The air-tight iron doors of the "dens" must slide easily backward or forward when the superphosphate has become dry enough to be dug out.

The tops of the "dens" are fitted with mixers of cylindrical shape about 10 feet long, 3 feet in diameter and 4 feet high. The mixer may be constructed of wood lined with sheet lead, or

of brick, or of iron, or in fact any suitable material in accordance with the fancy. It stands over the dividing wall of two "dens;" is generally provided with movable traps for discharging its contents at either of its ends and with a revolving axle or shaft fitted with arms or spirals. It should have a hopper and a gas-flue, and the driving gear must be of wrought-iron. Running into it from the



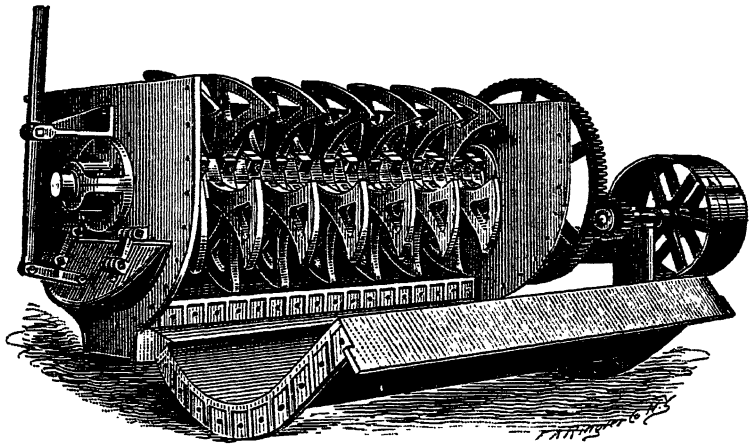
SIDE VIEW OF A SUPERPHOSPHATE WORKS.

A, Discharge from mixer to "den." 1, 2, 3, 4, Exit-flues conducting fumes to condenser.

top directly under the hopper is a 2-inch lead pipe fitted with a stop-cock and connected with a tank of sulphuric acid placed directly overhead. The acid tank is provided with a gauge which shows the exact amount of liquid run into each batch as required by calculation. The tank communicates in its turn with the acid reservoirs from which, when emptied, it is replenished by a pump. The phosphate is brought forward from the mill in buckets on an

endless chain. Each bucket holds a known weight of material and each empties itself into the hopper of the mixer. Where there is no convenience for establishing an endless chain, the material can be carried to the hopper in sacks direct from the mill. When this hopper contains 1000 pounds of the powder, the acid tap underneath it is turned on, the agitators of the mixer are set in motion, and then the powder is allowed to run in a steady stream from the hopper.

When all the acid and the phosphate are in the mixer, the agitators are made to revolve with swiftness and energy for about two minutes, after which the trap of the mixer is opened and its



SUPERPHOSPHATE MIXER.

contents, a thick mud or mortar-like mass, are shot from it into one of the "dens" at its either extremity.

These operations are repeated until the "den" is full, care being taken to keep the gas-flues open and to see that the acid always runs into the mixer in advance of the powder. A neglect of the latter precaution invariably results in serious difficulties from clogging.

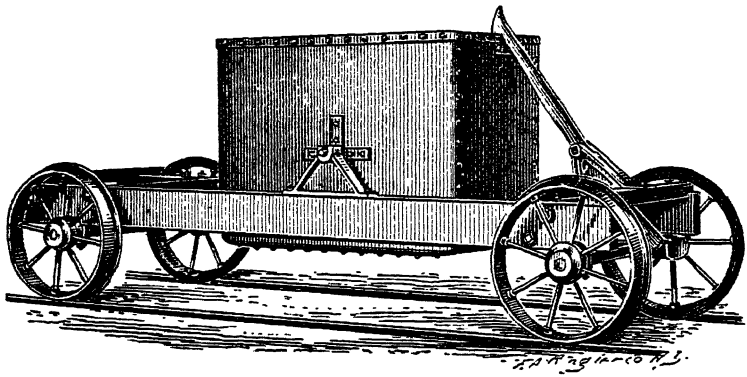
Each charge should be equal to an average of about 1900 pounds, and each "den" should hold about 120 tons. Assuming, therefore, the length of time required for running a charge to be five minutes, it is an easy matter to fill up a "den" each day of ten working hours.

The mixed mass enters the "dens" in a semi-liquid state and

soon becomes extremely hot, generally attaining a temperature of from 230° to 240° F. When properly composed it commences to "set" almost at once, and at the end of the second day is sufficiently hard to be dug out of the "den" with picks and shovels.

In this state it is loaded into automatic dumping-cars and piled up in heaps, all large lumps being broken down by a blow from the shovel. In a couple of days it is ready to pass through a disintegrator and may then be put up in bags.

The average superphosphate manufactured in this country contains about thirteen to fourteen per cent. of "available" P_2O_5, but the rapid development of the industry during the past few years has led to the introduction of what are known as "high-



AUTOMATIC DUMPING CAR FOR SUPERPHOSPHATE WORKS.

grade supers," containing about forty-five per cent. of phosphoric anhydride (P_2O_5) in a "water" and "citrate" soluble form. The plan upon which these goods are produced is perfectly scientific and rational, much more so, in fact, than the one we have just described, for it consists in using phosphoric acid as the solvent in lieu of the oil of vitriol.

The theory of the action of phosphoric acid upon pure phosphate of lime may be explained by either of the two following simple equations, or, to speak more correctly, by a combination of both of them :

$Ca_3P_2O_8$	+	$4(H_3PO_4)$	+	$6H_2O$	$= 3\,CaH_4(PO_4)2(H_2O)2$
1 insoluble tri-calcic phosphate	+	4 phosphoric	+	6 water	= 3 crystallized "acid" or "soluble" phosphate.

$2\,Ca_3P_2O_8$	+ $2\,(H_3PO_4)$	+ $12\,H_2O$	= $3\,Ca_2H_2(PO_4)2(H_2O)4$.
2 insoluble tricalcic phosphate	+ 2 phosphoric acid	+ 12 water	= 3 crystallized neutral phosphate, soluble in neutral citrate of ammonia.

The advantages offered by the cheap production of such an article as this in commercial form are, of course, too manifest to need any elaborate explanation, but it may nevertheless not be out of place to mention a few of them.

In the manufacture of superphosphates we have seen that the desired solubility, either in water or in citrate of ammonia, is attained at the cost of doubling the bulk of the raw material by the addition of an acid which practically serves no other purpose and has no other value than as a dissolvent. If the original material, therefore, contain sixty per cent. of tricalcic phosphate, the "super" can only contain thirty per cent., and this, from the agricultural consumers' standpoint, is certainly an anomaly, and, apart from any question of solubility, must remain so for two reasons:

1. A ton of sixty-per-cent. phosphate of lime, finely ground but insoluble in water or citrate of ammonia, can be purchased at some central point for, say, $10.

2. A ton of superphosphate, containing only thirty per cent. phosphate of lime, cannot be purchased at the same spot for less than $15.

In the one case, freight is paid upon only forty per cent. of inert material, whereas in the other it is paid upon seventy per cent.

Apart from the perfectly legitimate profits attached to the manipulation and transformation of a sluggish into an active body, those who at present derive the greatest benefit from the trade in fertilizers are the railroad companies. If it were for no other object than the reduction of freight charges to a minimum limit, it is consequently worth while to consider the advisability of substituting for the old method of manufacture, the one which we shall now attempt to describe.

The details of superphosphate mixing, and the reactions involved in the process, have been gone over in a sufficiently ample manner to prepare the way for the statement, that the cheapest and best-known method of producing phosphoric acid is by displacing it from its combination with phosphates of lime by means of oil of vitriol.

The proportion of phosphoric acid contained in the raw material being a matter of only relative importance, the adoption of such a

method would open up a channel for the use of many low-grade phosphates, which now, for lack of a market, are practically of no value. The only essential conditions to be fulfilled are:

A. That the material shall contain a minimum of carbonate of lime, in order that no unnecessary excess of sulphuric acid need be used.

B. That it shall contain as small a percentage as possible of any combination of iron and alumina, both of which, besides being difficultly soluble, contribute to the formation of a gelatinous mass that seriously interferes with the proper carrying out of the operations.

In order to ascertain the quantity of sulphuric acid necessary to insure the desired reaction, it is of course essential that the exact composition of the raw material be first determined by a reliable analysis. Supposing ourselves to be in possession of this information, we may imagine that we are called upon to deal with a mineral phosphate containing:

Moisture and organic matter	4.00
Phosphate of lime	55.00
Carbonate of lime	3.50
Phosphates of iron and alumina	6.50
Carbonate of magnesia	0.75
Fluoride of lime	2.25
Sandy and siliceous matters	28.00
	100

The quantity of oil of vitriol of various strengths required for the *complete liberation of all the phosphoric acid*, and the satisfaction of all the bases in such a sample as this, is very readily calculated from the figures in the following table:

TABLE SHOWING THE AMOUNT OF CHAMBER SULPHURIC ACID OF VARIOUS STRENGTHS REQUIRED IN THE MANUFACTURE OF PHOSPHORIC ACID FROM NATURAL PHOSPHATES.

Every pound of the following substances requires—	Acid at 48° B. Pounds.	Acid at 49° B. Pounds.	Acid at 50° B. Pounds.	Acid at 51° B. Pounds.	Acid at 52° B. Pounds.	Acid at 53° B. Pounds.	Acid at 54° B. Pounds.	Acid at 55° B. Pounds.
Tricalcic phosphate of lime	1.590	1.554	1.517	1.482	1.446	1.408	1.382	1.352
Carbonate of lime	1.640	1.605	1.565	1.535	1.495	1.456	1.428	1.411
Phosphate of iron	1.630	1.595	1.558	1.521	1.485	1.446	1.420	1.390
Phosphate of alumina	2.025	2.008	1.930	1.884	1.839	1.790	1.756	1.721
Carbonate of magnesia	1.940	1.905	1.860	1.815	1.775	1.726	1.690	1.660
Fluoride of lime	2.006	2.059	2.010	1.962	1.916	1.866	1.830	1.794

Selecting an acid strength of 50° B. for our illustration, we shall find that our sum will work out thus:

55	lbs.	phosphate of lime.....	× 1.517 =	83.44	lbs.	vitriol of 50° B.
3.50	"	carbonate of lime.....	× 1.565 =	5.48	"	" "
6.50	"	phosphate of iron and alumina	× 1.930 =	12.55	"	" "
0.75	"	carbonate of magnesia.....	× 1.860 =	1.40	"	" "
2.25	"	fluoride of lime.....	× 2.010 =	4.52	"	" "

Total sulphuric acid of 50° B. strength required for every 100 pounds of the above phosphate.....107.39 lbs.

The decomposition of the raw material is effected in large wooden tanks made of suitable wood and provided with wooden agitators.

2147 pounds 60° B. sulphuric acid are run into each tank and diluted with water until its strength is reduced to 14° B. The agitators are now set in active motion, and 2000 pounds of the phosphate, finely ground as directed for superphosphate manufacture, are slowly added and the stirring is continued for five hours. Open steam is occasionally blown in by an injector through the side of the tank, in order to keep up the temperature of the mixture.

At the end of the specified time the cream from each tank is run off into filters—large wooden vessels lined with lead and provided with false bottoms.

The hydrated sulphate of lime here separates from the solution of phosphoric acid, the latter passing through the filter as a bright straw-colored fluid, of a gravity which, at first, is about 12° B., but which gradually gets reduced by careful washing to 1° B.

By the exercise of ordinary care and precautions, all cracks on the surface of the gypsum contained in the filters may be avoided, for were they to be formed, too ready an outlet would be afforded for the washing-water. The washing is stopped directly the gravity reaches 1° B., and the hydrated sulphate of lime is first piled up in the centre of the filters to drain, and is then carried to the dump; the last runnings from the filters, which are too weak for economical concentration—everything under 5° B.—being used to dilute the sulphuric acid in subsequent operations.

If the wooden tanks be put up on the large scale in series of ten, a batch of the emulsion can be discharged from them, one after the other, every half-hour, when once they are all in proper working order, and in this manner twenty tons of phosphate can be treated per day.

All the phosphoric-acid liquor above 5° B. which has passed through the filters is blown by an "egg" (similar to the one described in the chapter on sulphuric acid) into an elevated tank, and thence it runs by gravitation to the evaporators, a series of leaden pans of any convenient form of construction, and heated either by a direct fire from the top or from the bottom or by the waste steam from the boilers. If any choice is to be awarded to either of these modes of evaporation, it must, in our opinion, fall upon top-heating; for as the hot gas comes into direct and immediate contact with the acid and the vapors produced are at once removed by the draught, it is evidently the quickest, while the pans are much less acted upon and freer from the danger of being burnt through than those which are fired from below. The vessel must, however, be kept constantly full and at a uniform level, in order to protect the lead from any direct contact with the flame; nor is this a matter of any difficulty, since the heavy concentrated acid continuously sinks downward, and may be drawn off from the bottom, in a stream directly proportionate to that in which fresh acid from the tank above is allowed to run in at the top.

In works where it is thought best to heat the pans from the bottom, the latter are generally so arranged in sets, that the weak acid flows in at one end in a regulated stream, and is transferred from pan to pan by overflow-pipes. The pans themselves in this case are placed on cast-iron plates, those at the fire end being very thick, to protect them from the extra heat, and generally lined with clay and fire-brick. The fireplace comes under the strongest of the pans, and the flame gradually travels towards the weakest, such an arrangement being required by the fact that the concentration becomes more difficult as the acid gains in strength. According to extensive and perfectly trustworthy experiments, a series of pans having a total area of 118 superficial feet, with a fireplace of 6½ superficial feet, can produce, when properly constructed, eight tons of phosphoric acid in twenty-four hours, concentrated to 45° B., with a consumption of no more than twelve to fourteen per cent. of its own weight of coal.

During the progress of the evaporation, the acid solution deposits a considerable quantity of sulphate of lime, and it is therefore generally necessary to decant off the fluid before the final degree of concentration can be attained. The gypsum can be removed to one of the filters already described, and washed out with any liquid that may be running into them from the mixing-tuns.

The finished liquid at 45° B. should contain nearly forty-five per cent. of phosphoric anhydride, with only a mere trace of lime. It will probably be contaminated to some extent by magnesia and iron and alumina, but neither of these, provided it is not present in any great quantity, will be a source of serious difficulty for the purpose in view.

We are now in possession of an acid body, which can take the place of sulphuric acid in the manufacture of soluble and assimilable phosphates, and we have only to come back to the old superphosphate mixers, and use the same modes of manipulation and the same system of calculation as in superphosphate manufacture. All that is needed is to change the numbers, in order to accord with the different composition of the two acids.

A raw phosphate of about the following composition may be taken as a typical material for economical treatment:

Moisture and organic matter	3.00
Phosphate of lime	75.00 (equal to 34.40 P_2O_5)
Carbonate of lime	7.50
Alumina and iron oxides (combined)	3.00
Fluorides, silicates and sand	11.50
	100

The quantity of phosphoric acid of 45° B. required to transform this insoluble phosphate into a "soluble" or readily "available" form may be taken from the annexed table. In calculating it we have assumed in a practical way, and without pretension to absolutely theoretical accuracy, that an acid solution of 45° B. "factory test" will contain, say, forty-two per cent. of phosphoric anhydride (P_2O_5) or about fifty-eight per cent. of phosphoric acid (H_3PO_4).

TABLE FOR USE IN THE MANUFACTURE OF HIGH-GRADE SUPERPHOSPHATES FROM PHOSPHORIC ACID OF 45° B.

Every Pound of the following Substances Requires for its Transformation	Into Water-Soluble or "Acid Phosphate."	Into Citrate-Soluble or Neutral Phosphate.
	Pounds.	Pounds.
Mineral phosphate of lime	2.310	0.625
Carbonate of lime	3.380	1.690
Iron oxide	.....	2.112
Alumina oxide	.....	3.270

We therefore proceed to ascertain that:

75 lbs. phosphate of lime...	× .625	require	46.88 lbs.	phosphoric acid.
7½ lbs. carbonate of lime..	× 1.690	"	12.68	" "
3 lbs. iron and alumina as oxides, say	× 3.000	"	9.00	" "
So that the total phosphoric-acid solution of 45° B. required to render 100 pounds of the above phosphate soluble in neutral citrate of ammonia is.....			68.56 pounds.	

This quantity being the known required minimum, it is easy after one or two trials of the drying capacity of the mixture, to increase it at will up to any desired limit, *it being evident that the more it is increased the greater will be the amount of "water-soluble" phosphate produced!*

The mixture, when made, is dropped, charge by charge, into the "dens," where it very soon sets into a porous mass, not quite dry, but sufficiently so to be easily dug out. This mass is cut up into pieces of reasonable size and dried by hot air, in sheds constructed for the purpose, in any form, or on any plan, that will facilitate effective and rapid work. Directly it is sufficiently dryfor the market it is put through a disintegrator and filled into bags.

In Europe the great superiority of this method of dealing with raw phosphates over the more generally established plan has been recognized for some years, and the high-grade product is much in vogue in Germany and France. The rough-and-ready plant which we have outlined has been supplemented in those countries by much labor-saving machinery in the form of mixers and filtering presses, the majority of which are protected by patent and chiefly manufactured in Germany, at Halle an der Saale. For the purposes of experimental demonstration, however, we have deemed it preferable to dispense with a description of all costly foreign apparatus, feeling that we may trust to the well-known genius of our American mechanical engineers for the construction of such plant as may be necessary in different localities, and under varying circumstances. When we bear in mind the proverbial conservatism of the farmer and his distaste for innovations, we shall see the necessity for going slow in this matter, for it will doubtless take some time to create an active demand from his direction for a concentrated superphosphate. Meantime, however, those who are engaged in handling fertilizers as middlemen will be more readily convinced, especially when they appreciate the economy in transportation, if in nothing else, which such a product will afford. How great this economy

really is can easily be shown by a few figures which, while not presented as the actual cost at which large and well-situated manufacturers could produce it, will suffice for purposes of illustration.

Commencing with the cost of phosphoric acid and assuming the factory to be located at a point within easy access by rail or by water, or both, we may calculate that

1 ton of 2000 pounds mineral phosphate, containing fifty to sixty per cent. phosphate of lime.....will cost	$4.00
Grinding same to a fineness of 70 to 80 mesh.. "	1.50
2130 pounds chamber sulphuric acid of 50° B. at, say, $7.00 per ton.....will cost	7.50
Labor of mixing and filtering, wear and tear, etc., calculated at the rate of, say, $1 per gross ton of raw material handled.....will cost	2.00
Concentration, labor, wear and tear of plant, calculated at $1 per gross ton of raw material.....will cost	2.00
Total net cost of producing, say, 1000 pounds of 45° B. phosphoric acid.....	$17.00
Cost of the 45° B. phosphoric acid per ton of 2000 pounds	$34.00

Passing now to the manufacture of *high-grade superphosphate* by decomposing the mineral phosphates with this acid instead of with chamber sulphuric acid, we shall find that it works out thus:

1 ton mineral phosphate, containing seventy-five to eighty per cent. tribasic phosphate, and of about the general composition shown in the examples selected for former calculations.....will cost	$14.50
Grinding same to 70 or 80 mesh..... "	1.50
1 ton phosphoric acid of 45° B..... "	34.00
Cost of mixing, manipulating, drying, pulverizing and bagging the finished material, calculated at $2 per ton of material used.....	5.00
	$55.00
The net product of the mixture after allowing fifteen per cent. for loss, by evaporation and in manufacture, will be, say, *thirty-four hundred pounds.* It will contain *fifteen hundred and thirty pounds* of phosphoric anhydride (P_2O_5) and costs.....	$55.00
Its cost per ton, ready for market, and containing forty-five per cent. of mixed *water-soluble* and *citrate-soluble phosphoric anhydride* will therefore be.....	$32.50

Or a little over 3½ cents per pound of phosphoric anhydride.

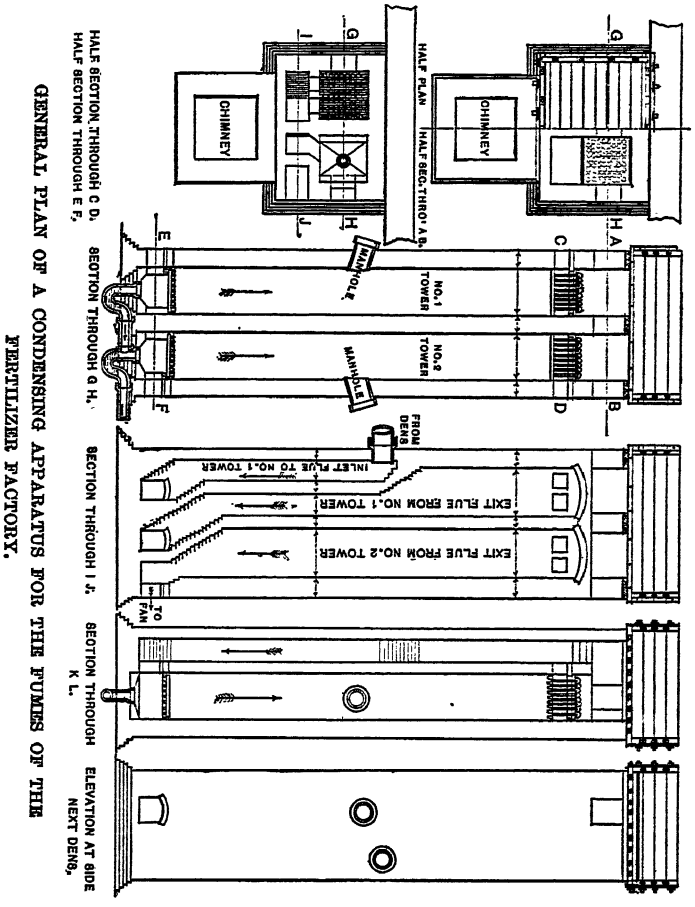
Since, as we have already explained, the great bulk of our superphosphate is not made to contain more than from twelve to fourteen per cent. of phosphoric acid soluble in water and ammonium citrate, and since it, for this reason, only represents on an average the equivalent of *thirty per cent. of bone phosphate of lime made soluble*, it necessarily follows that more than three tons of it would be required to equal one ton of the concentrated or high-grade material. The latter contains the equivalent of ninety-nine per cent. of bone phosphate of lime, made practically as soluble and equally available, and is therefore, as we have said, specially adapted to the requirements of the middleman. The distributer would only pay freight on one ton where he now pays it on three, and could, if he so desired, dilute it down to the ordinary commercial strength by the addition of gypsum, or any other convenient and low-priced filler.

A fruitful subject for angry discussion and costly litigation has been that bearing on the noxious vapors evolved during the manufacture of fertilizers from any of the phosphates we have described. It has been urged, and, to our minds, very consistently, that we should apply to them the same methods so successfully used in suppressing the devastating fumes from other chemical works, and there cannot be a doubt that if this were done, the present menace to the health and comfort of the workmen, and others employed in and about the neighborhood, would disappear.

As we have already pointed out, the fumes of fertilizer factories chiefly consist of carbonic acid, hydrofluoric acid, silicic tetrafluoride, sulphuric acid and steam; and of all these, the most dangerous to life and health are the compounds generated by the liberation of fluorine from the fluoride of calcium, the average proportion of which in our phosphates may be safely taken at about three per cent. The quantity of deadly vapor thus becomes very large in some of our big works, but it need not necessarily be alarming provided the gas-flues be properly worked. A ventilating-fan would easily conduct it all into the scrubber, where, meeting with a fine spray of very cold water, it would immediately be decomposed, hydrofluosilicic acid and gelatinous silica being formed. The acid could either be washed away into the main sewers or passed off into an open drain, and the finely divided silica could be allowed to deposit itself on the bottom of the condenser.

Mr. John Morrison, an English chemical engineer of great ability, who has done a great deal of valuable work in this connection

and devised the very practical scrubbing apparatus shown in the annexed sketch, says that the mixer fumes possess within themselves every element needed for their speedy destruction and but a single element (heat) to in any way retard it; and this is quite



GENERAL PLAN OF A CONDENSING APPARATUS FOR THE FUMES OF THE FERTILIZER FACTORY.

true. He objects, therefore, to the introduction of steam, on the ground that with every ton of superphosphate produced at least five per cent. of water in the form of steam is evolved, and as such a quantity is quite sufficient to saturate the effluent gases it is useless to employ any more. While a steam-jet will aid the draught; augment the agitation of the gases; and hasten the purification of

an atmosphere thickly laden with noxious vapors, it is nevertheless demonstrable that to the extent of the heat liberated in its own condensation, it retards the perfect filtration of the residual vapors, and any benefit accruing from its introduction is wholly disproportionate either to its quantity or its expense.

The most important point is to cool the gases by draughtage into chambers or flues of sufficient area or length, and where this can be managed economically little more is required, for the fume will quietly subside of itself. In the majority of cases, however, a maximum of condensing work must be accomplished in a minimum of space, and here the better way is to submit the gases to a sort of dry-scrubbing process so as to hasten the deposition of the fluorine compounds. How this is to be done must depend upon the special circumstances in each particular case, but there should always be provided, within a suitable flue, a sufficient number of impinging or baffling diaphragms, to momentarily arrest the motion of the gases and divert them into another direction, it being found that the greatest deposition of silica takes place at these eddying points.

The great bulk of the solid matter being thus early arrested, only the residual vapors now remain to be dealt with, and these are caused to traverse, in an upward direction, one or more water towers or wet scrubbers, simply packed with wood spars, to pass away to the chimney.

The necessary draught is created by an exhaust-fan of special construction actuated by the mixer engine. It is best fixed between the towers and the chimney, and its power is controlled by a damper just sufficiently to secure a slight "pull in" at the mixer mouth. The den doors are, of course, made as tight as possible to avoid unnecessary dilution of the gases and interference with the efficiency of the fan.

Gas dilution means reduced condensing efficiency. Yet there have been hosts of failures, due to a total misapprehension of the necessities of the case, and to the impracticable construction or wholly insufficient capacity of the condensing plant. In the erection of the latter two things have to be constantly borne in mind: First, that the evolution of the gas is spasmodic and (especially in the case of hot vitriol) extremely violent when the spasm is on; and, second, that every chokable part of the apparatus must admit of the readiest possible access. To provide for the first of these, the plant has to be of ample dimensions, and unless the second be

remembered, the most annoying failures will ensue at most inconvenient seasons.

Where such failures involve stoppages they are fatal to every semblance of manufacturing economy, since every unnecessary reduction in the day's dissolving tonnage, adds to the cost and diminishes the profits.

The wet scrubbers are packed with wood spars for two reasons: First, because spars exert no thrust on the tower sides and so save the necessity of tie-rods; and, secondly, because they seem to afford a maximum of interstitial, or scrubbing surface, to a minimum of solidity. The fire-brick packing sometimes adopted is less economical, for it not only largely augments the dead-weight of the towers, but decreases the ratio of useful surface to solid material by its pigeon-hole overlap.

The spars are made of wedged section, in order to delay the choking of the towers, both by affording extra space for the deposit of silica, and by facilitating its detachment and conveyance to the tower base by the action of the water. Silica deposited on the sides of square-sectioned spars, clogs the tower by reducing the packing spaces, whereas on wedged-section spars, a considerable deposit can take place without at all affecting the packing-mesh.

Where economy of water is an object one tall tower is preferable to two or three shorter ones, but the best arrangement is a tower of moderate height, divided into two packed upcasts, with a downcast flue between

CHAPTER VIII.

SELECTED METHODS OF PHOSPHATE ANALYSIS AND GENERALLY USEFUL LABORATORY DETAILS.

THE world's consumption of mineral phosphates and superphosphates from all sources, amounts to several million tons a year. The commercial value, alike of these natural and artificial products, depends upon their percentage of phosphoric acid, and upon their freedom from certain undesirable or injurious constituents as revealed by chemical analysis.

The miner, the manufacturer, and the farmer, are hence equally dependent upon the analytical chemist, whose province it is to determine how much the two first shall receive, and how much the last shall pay for the merchandise. The responsibility is a heavy one for the analyst, and he must either justify it or bring a great deal of discredit upon his profession.

We know that chemistry is the most precise of the sciences. It is not only capable of producing exact results, but it can foretell with unerring certainty, even before an operation is commenced, what those results will be. Complete concordance in phosphate analysis should consequently be "a thing of course," and a dozen chemists in as many different parts of the globe have no right to differ in the second decimal in their findings on the same sample.

An average error of no greater importance than say one unit of phosphate of lime, worth 20 cents, would entail, when spread over a total year's consumption of raw material, a cash difference of about $300,000. This difference, of course, constitutes a loss, which is sometimes borne by the miners who sell, and sometimes by the manufacturers who buy.

We have seen that in certain cases where superphosphates are sold on the basis of their water-soluble phosphoric acid, iron and alumina phosphates as a raw material, have no commercial value. Any widely differing results obtained by chemists in their determinations of these bodies in shipments of mineral phosphates, therefore, may cause infinite trouble between miners and manufacturers.

At the present time there prevails between the contracting

parties, what appears upon its face to be an equitable arrangement in this connection. The market price of the phosphate rock is fixed at a certain sum per unit of phosphate of lime, and it is agreed that this rock may contain a certain amount of oxides of iron and alumina without affecting its price. This *tolerated amount*, however, must not exceed three per cent. by weight of the mass, and every additional per cent. of oxides of iron and alumina is to be compensated for by a proportionate deduction from the total quantity of phosphate of lime.

To justify such a deduction, it is necessary to remember that in the initial stage of superphosphate manufacture, a great deal of free phosphoric acid is produced, which, in the presence of oxides of iron and alumina, enters into combination with them to form phosphates in the following proportions:

Oxide of iron to phosphoric anhydride.....	1 : 0,88
Oxide of alumina to phosphoric anhydride.....	1 : 1,37
Ratio of the equally combined oxides to the acid.....	1 : 1,13

It follows from this that every per cent. of these equally combined oxides causes 1.13 per cent. of phosphoric anhydride (P_2O_5) to become insoluble in water. Where "reverted" phosphates are valueless, therefore, the European manufacturer is justified in declining to pay for what will bring him no return for his money.

A working example of this arrangement may serve to make it more clear, and will specially emphasize the necessity for conformity of analysis between shipper and consignee. We give an instance which actually turned out as follows:

A cargo of phosphate rock was shipped from one of our ports to Liverpool, in fulfilment of a contract, embodying the above arrangement in regard to iron and alumina, and fixing the price of the material at 25 cents per unit of phosphate of lime.

The analysis of the cargo (1000 tons) by the chemists at the ports of shipment, and arrival, respectively, showed the following variations:

	Shipment.	*Arrival.*
Phosphate of lime.....	78.30	77.10
Oxides of iron and alumina (combined).....	2.95	5.01

These results were contested by the shippers, and the sealed samples, taken and reserved at both ports, were handed to four

reputable chemists. Two of these were in New York and two in London, and the following were the results of their work:

	SHIPPING SAMPLE.		ARRIVAL SAMPLE.	
	Phosphate of Lime.	Oxides of Iron and Alumina.	Phosphate of Lime.	Oxides of Iron and Alumina.
New York chemist No. 1.....	77.80	3.70	76.95	4.86
New York chemist No. 2.....	77.40	4.01	77.30	4.22
London chemist No. 1.....	78.01	3.95	76.80	4.90
London chemist No. 2.....	77.25	4.15	77.15	5.12

These figures were, of course, unsatisfactory in themselves, but they made it clear that the greatest error had been made, in the first instance, by the shippers' chemist, and it was consequently arranged that the cargo should be paid for on the averages of the three English chemists, which were:

Phosphate of lime..... 77 per cent.
Oxides of iron and alumina..... 5 "

The original invoices had been made out by the shippers on the basis of their own analysis at the price of $19.25 per ton, but the final settlement stood thus:

Oxides of iron and alumina found by analysis..... 5 per cent.
" " " allowed by contract..... 3 "
" " " to be paid for by sellers. 2 "
1 : 1,18 : : 2 : 2.26 phosphoric anhydride.

The factor for converting phosphoric anhydride (P_2O_5) into phosphate of lime is 2.18—consequently $2.26 \times 2.18 = 4.92$ phosphate of lime.

SETTLEMENT OF INVOICE.

Phosphate of lime found by analysis..... 77 per cent.
Deduct the equivalent of two per cent. iron and alumina as above..... 4.92 "
Total phosphate to be paid for at 25 c. per unit... 72.08 "
Value of the phosphate per ton, $18.

The difference between the amount of the original invoice and that of the settlement was therefore $1250.

How are we to account for these divergencies? Must they be put down to carelessness, incapacity, inexperience, bad faith, or must

we attribute them, as we have already suggested, to the faulty methods of sampling at either or both ends, and to the lack of a uniform method by which all chemists should agree to work? The first four factors perhaps require to be counted with, but there is no doubt in our minds that the two last are the real causes of the trouble, and we have long endeavored to bring about an agreement that would go far in causing them to diminish or disappear. If chemists were not human, or if they were entirely superior to petty prejudices, an *entente cordiale* might not be very difficult. Unfortunately, however, every individual is prone to regard his own work as irreproachable, and from that very fact to look upon any outside suggestions of modification as presumptuous and unnecessary. In a former chapter we pointed out the advisability of chemists coming together and arriving at a definite understanding, but if all hope of this is to be finally abandoned as impracticable, there is still one way open by which to establish and enforce a method that shall alone be used in the settlement of phosphate affairs. The mine-owners must act in unison and fix their own basis for sampling, analyzing and valuation.

There is no reason why the interests of the manufacturer should differ from those of the producer. If phosphate of lime in the required form be worth a certain price per unit, why should a door be left open to chicanery when the time comes to pay for it? Why should there be any material difference between the shippers' and the buyers' samples, if both are faithfully taken according to prescribed rules and with a proper regard for the true interests of each party to the contract?

Whatever method of analysis be chosen, it must be accompanied by complete details of laboratory manipulation. The observance of these details should be insisted upon, and must be communicated to all the various chemical and industrial societies in order that they may be expeditiously and officially brought before analytical chemists all over the world. All contracts between miners and manufacturers should contain a special clause specifying that

"The phosphate sold under this contract shall be paid for at the rate of ..... per unit and per ton of phosphate of lime, and shall not contain more than a maximum of ..... per cent. of iron and alumina, calculated as oxides, on the dry basis. Every unit of these oxides, singly or combined, in excess of the maximum, shall be deemed to neutralize two units of the phosphate of lime, and

such excess shall therefore be deducted from the total phosphate of lime found in the results of chemical analysis.

"This chemical analysis shall be made in duplicate, from the same sample, by two chemists, one representing the buyer and the other the seller, and it shall be performed in strict accordance with the method, in all its details, hereunder set forth. If the two analyses only exhibit on their face a maximum difference equalling one per cent. of phosphate of lime, such difference shall be adjusted by taking the mean of the two results; but in case the difference should exceed this maximum, a third analysis shall be made by another chemist, to be mutually agreed upon by the contracting parties, and the settlement shall then and there take place upon the basis of an average between the results of this third analysis and those of that one of the other two first chemists which was nearest to its figures."

EXAMPLE.

	Phosphate of Lime.	*Oxides of Iron and Alumina.*
Chemist No. 1 finds.....	78.20	2.85
" " 2 "	76.30	2.70
" " 3 "	77.40	3.00
Average of Nos. 1 and 3	77.80	2.92

To strengthen these preliminary suggestions we will now set forth what we regard as the best and the most practical methods of sampling and analysis. These methods are being constantly employed in our own work, and while we claim no originality for them, they have stood the test of our experience in many fields and on *every variety of material* with perfect satisfaction.

SAMPLING.

As this work is generally undertaken rather by practical workingmen than by analytical chemists, it is deemed advisable to point out, in the plainest possible way, the easiest, most effective and accurate method of conducting it. Nor need we dwell upon the importance of this operation and the necessity for its being carefully supervised by all capable managers, for we have already shown that enormous losses have continually been made and must ever surely result from ignoring or disregarding details.

When the phosphates are sampled upon the mine for the control of the daily work, it is necessary to take them from the piles. The latter are therefore very carefully gone over, and averages are

selected from their every part and placed aside until, in the opinion of the sampler, a sufficient quantity has been amassed to make it representative. The big lumps are then all broken up with a hammer, and the entire material is spread out upon the surface of a level floor, well mixed up, and passed through a crusher to reduce all the lumps to a small uniform size. It is then again spread upon the floor, shovelled up in a circular direction into a cone-like heap and then once more spread out flat. About a fourth part is next separated from the whole by taking out with a spade two strips crossed at right angles, and adding a small portion from each remaining quadrant. This fourth is made to go through the same process of spreading, heaping and dividing into fourths until the last operation leaves no more than about five pounds, which, after thorough mixing on a table, is ground to an impalpably fine powder, emptied into wide-mouthed bottles, well corked, securely sealed and labelled.

When the sampling takes place either at the port of shipment or discharge, it must not be lost sight of that the result is to form the basis of the price per ton which the miner is to realize for his cargo. It has, therefore, to be performed in the presence of trusted and reliable representatives of both seller and buyer. If the loading and unloading is done by means of buckets, every twentieth bucket of the whole cargo is set aside. The entire sample is then passed through a stone-crusher in order to reduce all the lumps to a very small size, and is then spread out upon a level floor and tossed up into a heap and treated in the same general way as described for the smaller sample at the mines. When it has been reduced, however, in the present case, to about five tons, it is taken to a mill, ground to a fineness of 80 mesh, and filled into bags of 200 pounds capacity, which are securely tied and placed in a row. Each one of these fifty sacks is then sampled at both ends by means of a sharp-pointed augur, 18 inches long and 1½ inches diameter, which is first plunged into the top and then into the bottom for its entire length, being emptied of its contents into a large tin plate by giving it a tap on the side after each operation. When all the sacks have been sampled in this way, the powder is thoroughly mixed by passing it through a sieve twice or even three times, and is then divided into three equal parts, each of which is put in a wide-mouthed glass bottle and sealed with the seal of both parties to the contract. One of these samples is handed over to some public officer, or other party mutually

agreed upon for safe-keeping in case of dispute; the other two are taken, one by each of the contracting parties, for the purposes of analysis.

ANALYSIS OF MINERAL PHOSPHATES—APATITE, PHOSPHORITE, COPROLITE, ETC.

The sample must bear the date upon which it was drawn, and must in every case be representative of the bulk. It must be clearly labelled with all particulars as to its origin and destination, including the name of the vessel or the number of the railroad car. When drawn as a working sample of the mine it must bear the mention "*average sample from Mine No.* .... drawn by ..... from piles No. .... representing ..... tons."

All these details are entered in the laboratory journal, and this having been done, the entire sample to be analyzed is first made to pass through a screen of 80 mesh by the analyst. The following determinations are then proceeded with:

Moisture.
Water of combination and organic matter.
Carbonic anhydride (CO_2).
Insoluble siliceous matters.
Phosphoric anhydride (P_2O_5).
Sulphuric anhydride (SO_3).
Fluorine (Fl).
Lime (CaO).
Magnesia (MgO).
Iron and alumina as oxides (combined).

Moisture.

Two grammes of the substance are very carefully weighed in accurately tared and well-ground watch-glasses. The latter are then adjusted with the clip so as to leave a sufficient opening for the passage of steam, and are placed in the gas-oven at 110° C. At the end of three hours the glasses are taken out, closed tightly, placed in the desiccator until quite cold, and then brought upon the scale.

The difference between the present and the original weight $\div 2$ = moisture in one gramme of the material.

Water of Combination and Organic Matter.

The residue from the moisture determination is carefully brushed into an accurately-tared platinum crucible. The crucible is placed

over a small Bunsen flame for ten minutes, and is then brought to a white heat by means of the blast. After being kept at this high temperature for five minutes the flame is removed, the crucible is covered; placed in the desiccator; and allowed to become quite cold. It is then weighed, and the difference between the present weight and that of the residue from the moisture determination ÷ 2 represents the "loss on ignition" in one gramme of the material.

The total of this loss on ignition includes water of combination, organic matter, and carbonic anhydride, and as the latter is to be determined separately, its weight when found must be deducted from this total.

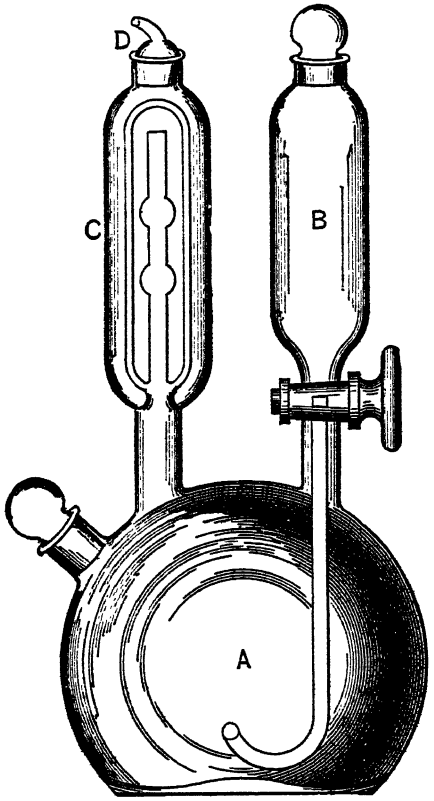
Carbonic Anhydride (CO_2).

This is one of the most essential of the determinations, and should be made in every sample destined for factory use. There are numerous excellent methods of performing it, but the two most commonly used in our laboratory are those of Scheibler and Schrötter. The first-named is based upon the principle that the quantity of carbonic anhydride contained in pure chalk can be used as a measure of the quantity of that salt itself. Instead of estimating the carbonic-acid gas by weight, therefore, this method allows of its estimation by volume, and when skilfully handled it yields very rapid and very accurate results. The second is a far simpler, and in our experience equally expeditious, method, and our students consequently take more readily to it than to the other. It only requires ordinary care in its manipulation to give perfect satisfaction.

A mere glance at the figure will suffice to show that the apparatus is made of blown glass, and that its principle depends upon the loss of weight which occurs in a carbonate when its carbonic-acid gas is expelled.

Two grammes of the original substance are accurately weighed and introduced into A. The tube B is now filled with fifty per cent. hydrochloric acid and the tube C about a quarter filled with concentrated sulphuric acid. All the stop-cocks have meantime been kept closed, and the apparatus is now brought upon the scale and very accurately weighed. The weight being noted in the agenda it is withdrawn from the scale, the stop-cock on tube B is gradually opened and the hydrochloric acid thus allowed to come into contact with the phosphate. When all the acid is in, the tap

is closed and the apparatus is allowed to stand in a warm place (say at 80° C.) for two hours with occasional agitation. The carbonic-acid gas passes off through C, the sulphuric acid, however, preventing the escape of any moisture that might otherwise accompany it. At the end of two hours B is opened, and the air



SCHRÖTTER'S APPARATUS FOR THE ESTIMATION OF CARBONIC-ACID GAS.

is drawn through the apparatus by suction applied to a piece of thin India-rubber tubing connected with D in order to sweep out all traces of the CO_2. B is then closed and the apparatus is allowed to become quite cold, when it is brought back to the scale and weighed. The difference between the present and the first weight ÷ 2 represents the CO_2 in one gramme of the normal sample.

EXAMPLE.

Weight of the carefully dried "Schrötter" charged with Two grammes Phosphate in A..... Diluted HCl in B..... Concentrated H_2SO_4 in C.....	33.672
Weight of the carefully dried apparatus at the end of two hours, after the prescribed manipulation.....	33.585
Loss in weight by 2 grammes phosphate.....	0.087

Equal 0.0435 in 1 gramme, or 4.35 per cent.

Insoluble Siliceous Matters.

Five grammes of the original sample in its normal state are accurately weighed out and placed in a porcelain dish with about 30 c.c. of aqua regia. The dish is placed upon a sand or air bath, covered with an inverted funnel, gradually heated, and evaporated to dryness; care being taken to avoid any spurting and consequent loss. As soon as it is dry, the residue is moistened with pure concentrated hydrochloric acid, and again evaporated to complete dryness, after which the heat of the bath is increased to 125° C. and so maintained for about ten minutes. When it has become cool the silica will all be insoluble, and the residue is treated with 50 c.c. of concentrated hydrochloric acid and allowed to remain in this contact for fifteen minutes. The acid is then diluted, filtered through an ashless filter, and the porcelain dish and the filter carefully washed with hot water until the filtrate measures 250 c.c. The residue on the filter, which should be quite white, is now dried in the oven, calcined and weighed. The weight $\div 5 =$ insoluble siliceous matter in 1 gramme of the material.

Sulphuric Anhydride (SO_3).

Twenty-five c.c. of the filtrate from the siliceous matter, representing 0.50 gramme of the phosphate, are placed in a beaker, boiled, and treated while boiling with 5 c.c. of a saturated solution of barium chloride. The hot liquid is brought upon a small ashless filter; the beaker and the filter are well washed with boiling water until the last washings show no trace of chlorides; and the filter is then dried, calcined and weighed. The weight $\times$ .3429 $\times 2 =$ sulphuric anhydride (SO_3) in 1 gramme of the material.

N.B.—The words "ashless filter" are used on this, and on all subsequent occasions, only in a comparative sense, and are meant to indicate the round cut filters, washed in hydrochloric and

hydrofluoric acids manufactured by Messrs. Schleicher & Schuell. These filter rapidly, retain the finest precipitates, and leave an ash which—in the No. 590, of 9 cubic centimetres diameter, for example —only amounts to 0.00008 gramme.

Phosphoric Anhydride (P_2O_5).

Twenty-five c.c. of the filtrate from the siliceous matter, representing 0.50 gramme of the phosphate, are placed in a beaker with 10 grammes ammonium nitrate. The solution is heated over a Bunsen or other smokeless flame, and when quite warm is treated with 150 c.c. of molybdic solution and well stirred. After digesting for one hour at 70° C., it is filtered and washed with water three or four times. The beaker in which the precipitation was made is now placed beneath the funnel; a small hole is made in the bottom of the filter-paper with the point of the stirring-rod, and the precipitate is washed from the filter into the beaker by means of a hot mixture of water and ammonia (5 : 1). If this washing is skilfully performed, the amount of liquid used will not exceed 75 c.c. in order to remove all traces of the ammonium-phospho-molybdate.

The filtrate having been nearly neutralized by the careful addition of hydrochloric acid until the yellow color only disappears with difficulty, is allowed to cool, and there are then added to it very slowly, in fact, drop by drop, 20 c.c. of magnesia mixture, stirring with a glass rod all the time. Finally, there are poured in about 50 c.c. of strong ammonia, the mixture is again stirred, and then allowed to stand for four hours. The precipitate is collected on an ashless filter, and the beaker is very thoroughly washed with dilute ammonia by means of a rubber tip on the glass rod. When all the liquid has passed through the filter, the latter is washed carefully twice, by blowing the dilute ammonia down its sides in a fine stream, and is then placed in the drying-oven. When quite dry, it is removed from the funnel, folded carefully in order to prevent loss of its contents, placed in a tared porcelain crucible, and ignited, at first very gently, but finally over the most intense obtainable flame, for ten minutes, in order that the residue may become white. The crucible is now covered, transferred with the tongs to the desiccator, allowed to become quite cold, and weighed. The weight of this magnesium pyrophosphate ($Mg_2P_2O_7$) $\times$ .6396 $\times$ 2 = phosphoric anhydride (P_2O_5) in 1 gramme of the material.

Fluorine (Fl).

This element may first of all be tested for, qualitatively, in order to save much unnecessary trouble.

Two or three grammes are placed in a platinum dish with about 2 c.c. of concentrated sulphuric acid. The dish is covered with a watch-glass thinly coated with wax, through which the operator may trace some mark with a fine needle-point Heat is then gently applied, and, at the end of, say, ten minutes the watch-glass is removed, and the wax upon it is washed off. The etching of the characters traced on the glass proves the presence of fluorine, and the analysis may be proceeded with as follows :

Five grammes of the finely-ground phosphate are fused in a platinum dish, with 15 grammes of the mixed carbonates of sodium and potassium, and 2 grammes of very fine sand. After fusing very thoroughly with a strong heat for a quarter of an hour, the dish is removed from the fire, cooled down, and its contents dissolved in hot water and treated with ammonium carbonate in excess, in order to remove the last trace of soluble silica. The liquid is now filtered and washed with great care ; the filtrate is nearly neutralized with hydrochloric acid and then treated with an excess of calcium chloride solution ($CaCl_2$).

The precipitate, consisting of phosphate, fluoride and some carbonate of lime, is washed several times by decantation with boiling water, collected on an ashless filter, dried and calcined. After being allowed to cool, the residue is treated with acetic acid and evaporated to dryness on the water-bath in order to transform the carbonate of lime into acetate of lime. The acetate is next well washed out with boiling water several times, and the final residue is brought on an ashless filter, dried, calcined and weighed. This time, the weight represents only the phosphate and fluoride of lime contained in the five grammes of the original sample.

After taking due note of this weight, the residue is returned to the platinum dish, 5 c.c. of concentrated sulphuric acid are added to it, heat is applied, and the fluorine is all driven off. When no more fumes are evolved, the source of heat is removed, the residue in the dish is treated with 100 c.c. alcohol, filtered and washed with alcohol up to 200 c.c.

The alcoholic filtrate contains the phosphoric acid, and this is precipitated as ammonio-magnesium phosphate. The precipitate

is washed, dried, calcined and weighed as $Mg_2P_2O_7$, every part of which $\times .1396 =$ phosphate of lime ($Ca_3P_2O_8$).

We now refer to our note-book to find the weight of the combined phosphate and fluoride of lime contained in the five grammes of the original sample asdetermined after the acetic-acid treatment, and by means of this weight we now make the following calculation:

EXAMPLE (TAKEN AT RANDOM FROM OUR AGENDA).

Weight of the residue of combined phosphate and fluoride of lime in 5 grammes of the sample.....	3.900
Weight of the phosphate of lime calculated from $Mg_2P_2O_7$.	3.775
Fluoride of lime, by difference in 5 grammes	0.125

Therefore $5 : .125 :: 100 : x = 2.50$ per cent. fluoride of lime, which $\times .4897 = 1.22$ per cent. *fluorine.*

Oxides of Iron and Alumina.

This highly-important determination is the object of much controversy, and may be roughly said to be the pivot upon which revolves very nearly every difference in the phosphate analyses of various chemists. A large number of schemes have been devised and experimented with, but only very few of them have proved worthy of general application.

The chief points required of a method for practical work are: that it should be accurate, that it should be easy and rapid, and finally, that it should be economical. All these we believe to be embodied in the following plan, which, when carried out with care and exactly as we shall describe it, produces constant and strictly concordant results. When left to our own choice we have always preferred it to any other for our own work, and many of our pupils and former assistants who have left us and are now employed either at phosphate mines or at fertilizer works throughout the country, continue to exactly accord in results with our laboratory. We consider this to be a great point in its favor, and it is in fact the one which mainly prompts us to so strongly recommend its general adoption.

Fifty c.c. of the filtrate from the siliceous matter, equalling one gramme of the phosphate, are placed in a beaker, made alkaline with ammonia, and diluted to 150 c.c. with distilled water.

Pure concentrated acetic acid must now be gradually added to the mixture until a drop of the latter produces a distinct redness when placed upon fresh and sensitive litmus paper. The mixture is stirred, and allowed to stand in a cool place *until perfectly cold.*

It is then filtered on an ashless filter, and the beaker and residue are carefully washed twice with hot water. The substance on the filter is now carefully dissolved in a little hot, fifty-per-cent. solution of hydrochloric acid, and the filter is washed with enough water to make up about 150 c.c. A few drops of a solution of phosphate of sodium are now added. In order to ensure the presence in the mixture of phosphoric acid in sufficient quantity to form phosphates with the iron and alumina. The contents of the beaker are next made alkaline with ammonia in slight excess; then made acid with pure concentrated acetic acid as in the first operation; well stirred up, and again allowed to stand until absolutely cold. The flask containing the first filtrate is now replaced under the funnel, the liquid in the beaker is filtered into it, and the filter is well washed with cold water containing a little acetic acid. The funnel containing the filter is now placed in the oven and completely dried, after which the filter and its contents are calcined, and weighed as *phosphates of iron and alumina in one gramme of the material.* For all the general purposes of the factory, or for the control of daily work at the mines, it is only necessary to divide the figure thus found by 2, and to state the result roughly as "oxides of iron and alumina (combined)." As we have given our reasons for this proceeding in an earlier part of this chapter, it is not necessary to repeat them, and we will content ourselves with a mere example.

The weight of the combined phosphates in one gramme was .058; then .058 ÷ 2 = .029 = 2.90 per cent. oxides of iron and alumina

When reporting upon a sample for commercial purposes that is to say, when determining its value to the manufacturer of water-soluble superphosphates, it is sometimes necessary to carry this analysis a little further. In such cases, after carefully noting the accurate weight of the combined phosphates, they are dissolved in boiling hydrochloric acid. The solution is filtered into a 100-c.c. flask and washed up to the mark with boiling water. No residue should remain on the filter save perhaps a speck or two of carbon resulting from the recent incineration. In one half of the filtrate, the phosphoric anhydride is determined by the molybdate method already described. The resulting $Mg_2P_2O_7 \times .6396 \times 2$ equals the P_2O_5 in one gramme of the combined phosphates.

The remaining half of the filtrate is boiled with a small piece of zinc in a flask fitted with a Bunsen valve. When the iron is completely reduced and gives no trace of pink coloration with potas-

sium sulphocyanate, the liquid is cooled, about one gramme of magnesium sulphate is dissolved in it, and it is then titrated with $\frac{1}{50}$ N. permanganate solution, every c.c. of which = .00080 ferric oxide. The number of c.c. used × 2 will represent the amount of iron oxide contained in one gramme of the above phosphates. Two out of the three constituents being thus accurately known, the third, which is the alumina, can easily be determined by difference, as for example:

Weight of the combined phosphates of iron and alumina..		.058
Phosphoric anhydride determined in the above.....	.031	
Iron oxide (Fe_2O_3) " "	.010	
		.041
Oxide of alumina (by difference).....		.017

In reporting upon the sample we should therefore state the presence of

Oxide of iron.....	1.00	per cent.
Oxide of alumina.....	1.70	"
Weight of these oxides combined.....	2.70	"

instead of the 2.90 per cent. which were obtained by merely dividing the combined phosphates by 2.

The only other method of determining the percentage of iron and alumina which has been used in our laboratory with satisfactory results, was recently adopted at the request of clients, and is generally known as the Glaser method, from its having been first suggested and described by a German chemist of that name (in *Ztschr. Angew. Chem.*, 89, 636). The way in which we carry it out, differs somewhat from the first description by its author, and is as follows:

Two and a half grammes of the phosphate are dissolved in 10 c.c. hydrochloric acid; evaporated to dryness; taken up again with hydrochloric acid, raised to boiling, and washed out into a 250-c.c. flask with as little water as possible. Ten c.c. concentrated sulphuric acid are now added, and the solution is allowed to stand for five minutes, with frequent shaking. After adding some ninety-five per cent. alcohol, the mixture is cooled, made up to the mark with alcohol, well shaken, and when the contraction in volume has taken place, is again made up to 250 c.c. and mixed. After standing one hour it is filtered, and 200 c.c. (= 2 grammes phosphate) are taken and gently

evaporated to a small bulk. When organic matter is present, it is desirable to evaporate to pastiness, that the acid may partially decompose it. The solution is now washed into a beaker with about 50 to 100 c.c. water; boiled for a short time with bromine or other oxidizing agent, as suggested by H. H. B. Shepherd (in *Chem. News*, 63, 251); and, after adding ammonia, it is again boiled for about half an hour. It is then cooled, and, after the addition of a little more ammonia, is filtered; washed with a hot solution of ammonium chloride to prevent the precipitate from passing through the filter; ignited, and weighed. The phosphoric acid is determined by dissolving the ignited precipitate, exactly as we have described in the former method, and the oxides of iron and alumina are obtained by difference. If magnesia is present, the phosphates of iron and alumina obtained as above must be freed from this impurity by washing the precipitate off the filter, and boiling with water and a little nitrate of ammonium.

As we have already stated, our own preferences are in favor of the first method, and this, not only because we believe it to be perfectly exact and reliable, when in the hands of a skilful operator, but because it is much more rapid and much less costly. We, however, have no positive objections to the Glaser scheme, and when carried out on the above lines should have every confidence in the accuracy of its results.

Lime (CaO).

The total filtrates from the iron and alumina determination first described are mixed by shaking the flask, and are then concentrated by boiling down to about 100 c.c. At this point there are added to the liquid about 20 c.c. of a saturated solution of ammonium oxalate, and the mixture, after stirring, is withdrawn from the fire, covered with a watch-glass and allowed to stand for six hours. At the end of this time the supernatant fluid is filtered through an ashless filter; the residue is washed three times by decantation with boiling water, and then brought upon the filter, and the beaker and filter are thoroughly washed at least three times more. The filter is then dried, taken from the funnel with the greatest care, placed in a tared platinum crucible, and ignited at a low red heat for ten minutes. At the end of this time it is brought to the highest possible temperature by the blast, kept there for five minutes, covered, and then rapidly removed to the desiccator. When quite cold it is weighed in the

covered crucible. The net weight = CaO in one gramme of the material.

It is customary in our laboratory to ignite and weigh this residue three times, or until the two last weights are identical.

Magnesia (MgO).

The filtrates and all the washings from the lime determination, as above detailed, are well shaken together, and concentrated by boiling to about 100 c.c.

After allowing the liquid to become quite cold, it is poured into a beaker, the flask carefully rinsed out into the same with distilled water, and the liquid made very strongly alkaline with ammonia.

After well stirring, the mixture is covered with a watch-glass and allowed to stand over night. The precipitate of ammonio-magnesium-phosphate is then carefully filtered through an ashless filter, the beaker thoroughly washed out with dilute ammonia by means of a rubber-tipped rod, and the washings brought on the filter. The latter is then finally washed twice with the ammonia water, placed in the drying-oven, calcined in a tared porcelain crucible, at first at a very low, then at the highest obtainable heat, and weighed as $Mg_2P_2O_7$. The weight × .360 = MgO in one gramme of the material.

If all the foregoing determinations have been performed with the required care, the quantities found should add up to a total very closely approximating 100. Assuming that this is the case, we suggest that a reliable opinion may at once be formed for the manufacturer, as to the industrial value of any mineral phosphate, by combining the various isolated bodies as follows:

The magnesia is multiplied by.....	2.10.	Result =	carbonate of magnesia.
The carbonic anhydride left over by the magnesia is multiplied by..	2.27	" =	carbonate of lime.
The fluorine is multiplied by.....	2.05	" =	fluoride of lime.
The sulphuric acid is multiplied by	0.75	" =	iron pyrites.
The lime remaining after satisfying the carbonic anhydride and fluorine is multiplied by.....	1.84	" =	phosphate of lime.
The phosphoric acid, if any, remaining after this satisfaction of lime is multiplied by.....	2.00	" =	phosphate of iron and alumina.

If all the phosphoric acid be used up by the lime available under this scheme, the iron and alumina may be regarded as having

existed in the form of silicates or clay, and, as we have pointed out in the chapter on Florida phosphates, our own experiments have very conclusively proved that in a majority of cases, they really do so exist. They would therefore be to a great extent unacted upon by the dilute chamber acid, used in the manufacture either of superphosphates or phosphoric acid.

ANALYSIS OF SUPERPHOSPHATES.

The sample should be well intermixed and properly prepared and passed through a sieve having circular perforations one-twenty-fifth of an inch in diameter, so that separate portions shall accurately represent the substance under examination, without loss or gain of moisture.

Moisture.

Two grammes are accurately weighed into the watch-glasses and heated for five hours at 100° in a steam-bath.

Water-soluble Phosphoric Anhydride.

Five grammes are weighed out into a small beaker; washed by decantation four or five times with not more than from 20 to 25 c.c. of water, and then rubbed up in the beaker with a rubber-tipped rod to a homogeneous paste, and washed four or five times by decantation with from 20 to 25 c.c. of water each time. These washings are all run through a 9-c.c.—No. 589 Schleicher and Schüell—filter into a 500-c.c. flask. The residue is finally transferred to the filter, and washed with water until the flask is filled up to the mark. The flask is now shaken, and 50 c.c. of the clear liquor, equal to ½ gramme of superphosphate, are transferred to a beaker, and treated with 150 c.c. of molybdic solution. The mixture is digested at 80° C. for one hour, filtered and washed with water. After testing the filtrate for P_2O_5 by renewed digestion and addition of more molybdic solution, the precipitate is dissolved on the filter with ammonia and hot water (as described in the analysis of raw phosphate) and washed into a beaker to a bulk of not more than 100 c.c. It is nearly neutralized with hydrochloric acid, cooled, and magnesia mixture is added slowly from a burette (one drop per second), with vigorous stirring. After fifteen minutes 30 c.c. of ammonia solution of density .95 are added, and the whole is allowed to stand for two hours. It is then filtered on an ash-

less filter, washed as in the case of raw phosphates, dried, calcined in a porcelain crucible and weighed as $Mg_2P_2O_7$. The weight of the residue × .6396 × 2 = the *water-soluble phosphoric anhydride* in one gramme of the superphosphate.

Citrate-insoluble Phosphoric Anhydride.

The residue from the treatment with water is washed into a 200-c.c. flask, with 100 c.c. of strictly neutral ammonium citrate solution of density 1.09. The flask is securely corked and placed in a water-bath, the water of which stands at 65° C. (The water-bath should be of such a size that the introduction of the cold flask may not cause a reduction of the temperature of the bath of more than 2° C.)

The temperature of 65° C. is maintained for thirty minutes, with vigorous shaking of the flask every five minutes. The warm solution in the flask is then filtered quickly and washed with water of ordinary temperature. The filter is transferred, with its contents, to a capsule, and ignited until the organic matter is destroyed. It is then treated with 10 to 15 c.c. of concentrated hydrochloric acid; digested over a low flame until the phosphate is dissolved; diluted to 200 c.c. mixed, and passed through a dry filter. One hundred c.c. of it are nearly neutralized with ammonia; 10 grammes of ammonium nitrate are added; the liquid is made quite warm and there are then added to it 150 c.c. molybdic solution. The process is completed exactly the same way as with raw phosphates.

The weight of the $Mg_2P_2O_7$ × .6396 × 2 ÷ 5 equals the *citrate-insoluble phosphoric anhydride in one gramme* of the substance.

Total Phosphoric Anhydride.

Two grammes of the superphosphate are weighed with great accuracy and treated in a porcelain capsule with 30 c.c. concentrated hydrochloric acid. Heat is applied and there is added cautiously, and in small quantities at a time, about .5 gramme of finely-pulverized potassium chlorate.

The mixture is gently boiled until all phosphates are dissolved and all organic matter destroyed, and is then diluted to 200 c.c., mixed and passed through a dry filter. Fifty c.c. of filtrate—equal to half a gramme of the superphosphate—are then taken and neutralized with ammonia, and about 15 grammes of dry ammonium nitrate are added. The solution is now made warm; 150 c.c. molybdic solution are added, and thenceforward the process is conducted exactly as in the case of raw phosphates.

The weight of the $Mg_2P_2O_7 \times .6396 \times 2$ equals the *total phosphoric anhydride* in one gramme of the substance.

The three following determinations have now been made:

1. The P_2O_5 soluble in water.
2. The P_2O_5 insoluble in ammonium citrate.
3. The total P_2O_5 contained in the substance.

The figures obtained in the first two cases, added together and deducted from the last, will therefore show the amount of citrate-soluble phosphoric acid in one gramme of the substance; as for example:

Total P_2O_5 in one gramme		0.160 gramme
P_2O_5 soluble in water	0.140	
P_2O_5 insoluble in water and ammonium citrate	0.004	.144 "
P_2O_5 soluble in ammonium citrate		.016 "

and the manner in which we should state the result of such an analysis as this in our reports would be as follows:

Moisture	?
Water-soluble phosphoric anhydride (P_2O_5)	14.00
Citrate-soluble or assimilable phosphoric anhydride (P_2O_5)	1.60
Insoluble phosphoric anhydride (P_2O_5)	0.40

Equal to 34 per cent. of bone phosphate made soluble.

THE VOLUMETRIC ESTIMATION OF PHOSPHORIC ACID.

While we have long discarded the use, in our commercial laboratory, of all volumetric processes of determining phosphoric acid for commercial purposes, we nevertheless have always found the one that we shall now describe of considerable value in the factory. With a little practice it is possible to observe the end reaction with great accuracy, and provided not more than one per cent. of combined iron and alumina is present, the results are tolerably reliable.

The formulæ for preparing the standard solutions required are given on another page, and the principle on which the method is based is the fact, that phosphoric anhydride and uranic oxide combine together to form a compound insoluble in acetic acid.

$$P_2O_5 + 2\ Ur_2O_3 = Ur_4P_2O_{11}$$
$$142 + 576 = 718.$$

It follows, therefore, that if a solution of phosphoric anhydride in acetic acid, be treated with a solution of uranic acetate, the P_2O_5 is precipitated, and it has been found that the slightest excess of uranic acetate can be detected in the mixture, by bringing a drop of it into contact with a drop of freshly-prepared solution of potassium-ferrocyanide, and noting the reddish-brown color produced. The first step being to establish the accuracy of the solutions, 50 c.c. of the standard solution of sodic phosphate are run into a small beaker; made akaline with ammonia; and then distinctly acid with acetic acid. Five c.c. of the sodic-acetate solution are now run into the mixture with a pipette; the beaker is brought over the flame of a Bunsen burner and the contents heated to about 70° C. When this point is attained the uranic-acetate solution is run in very cautiously, drop by drop, from a burette, until a drop of the mixture in the beaker taken out and placed in contact with a drop of the ferrocyanide solution, on a white porcelain slab or plate, gives a slight, but yet distinct, reddish-brown color.

When the necessary point has been attained—which generally requires two or three trials—the uranic solution is so arranged by dilution, or calculation, as to make 1 c.c. of it correspond to exactly 1 c.c. of the standard sodic-phosphate solution; in other words, to .002 P_2O_5.

The accurate standardization being completed, the sample of mineral phosphate to be examined is now weighed out. One gramme is dissolved in nitric or hydrochloric acid in the usual way, and with the usual precautions is filtered and washed to about 200 c.c. Fifty c.c. (equal to .250 gramme phosphate) are now placed in a beaker, made alkaline with ammonia, then strongly acid with acetic acid and treated with 5 c.c. of sodium-acetate solution. The mixture is then heated to 70° C., and at this temperature the uranium solution is run in, drop by drop, until the color reaction on the white plate is plainly visible. A second titration is made on another 50 c.c. of the solution of phosphate, and if the results are the same the operation is ended. Every c.c. of the uranic-acetate solution used equals .002 gramme P_2O_5 in .250 gramme of the material.

As will have been gathered from our opening remarks, the results of this process, as we describe it, are seriously vitiated by the presence of more than one per cent. of iron and alumina. When, however, these two bodies are present in any considerable amount there is a way out of the difficulty afforded by the fact

that they will remain precipitated in the acetic-acid solution as phosphates, especially in the presence of sodic acetate. When the liquid has become quite cold, therefore, they can be filtered off, washed, redissolved in hydrochloric acid, treated again with ammonia and acetic acid, made cold, filtered, washed, dried, calcined and weighed as iron and alumina phosphates.

If the filtrates from these operations be mixed together and heated to 70° C., they may be titrated with uranic solution as usual, and the quantity of P_2O_5 found by titration, added to half the weight of the phosphates of iron and alumina, will give, very approximately, the total amount of phosphoric anhydride in the original substance.

ANALYSIS OF PYRITES FOR SULPHURIC-ACID MANUFACTURE.

The sample is drawn from bulk in much the same manner as that described for the sampling of phosphates, and is ground to the fineness of 100 mesh, care being taken that every particle passes through the screen. The requisite quantity, say eight ounces, is now put into a wide-mouthed bottle provided with a tight-fitting rubber stopper, and the analysis is proceeded with.

The necessary determinations in the pyrites most ordinarily used in this country for acid manufacture are:

Moisture.
Siliceous matters.
Sulphur.
Iron.
Copper.

Moisture.

One gramme of the sample is weighed between two tightly-ground watch-glasses of which the tare, including the clip, is accurately known. The necessary space to allow for evaporation having been adjusted, the glasses containing the powder are placed in the gas-oven and kept at 110° C. until no further loss of weight is observed. Three weighings should be made at intervals of about one hour. The difference between the original, and the final

weight of the pyrites, and watch-glasses, represents the moisture in the sample.

Siliceous Matter and Silicates.

One gramme of the original sample is treated with about 20 c.c. of a mixture of three vols. nitric acid (specific gravity 1.4) and one vol. strong hydrochloric acid, both ascertained to be absolutely free from sulphuric acid. All spurting is carefully avoided and heat is gently applied, and the mixture evaporated to dryness in a water-bath; 5 c.c. of hydrochloric acid are now added, and once more evaporated (no nitrous fumes ought to escape now), and finally the dried residue is treated with a little concentrated hydrochloric acid and 100 c.c. of hot water and filtered through a small filter and washed with hot water. The insoluble residue on the filter is dried, ignited and weighed. It may contain besides silicic acid and silicates some sulphates of barium, lead and calcium, but these may be disregarded.

Sulphur.

The filtrate and washings from the last determination, are slightly saturated with ammonia, filtered while hot, and washed on the filter with hot water, avoiding channels in the mass. Sufficiently dense, but yet rapidly-filtering paper, must be used, and choice made of funnels with an angle of exactly 60°, whose tube is not too wide, and is completely filled by the liquid running through. The washing is continued until the addition of a little $BaCl^2$ to the last runnings shows no opalescence even after a few minutes. The filtrate and washings must not exceed 200 c.c., or if they do, they should be concentrated by evaporation. Pure HCl in *very slight excess* is now added; the liquid is heated to boiling; removed from the burner; and treated with 40 c.c. of a ten-per-cent. solution of $BaCl_2$, previously heated to boiling. After precipitation the liquid is left to stand for half an hour, when the precipitate should be completely settled. The clear portion is decanted through a filter, and the precipitate is washed with hot water by decantation three or four times, until the liquid loses all acid reaction. It should then be washed on to the filter, dried, ignited and weighed. Its weight $\times .1372 =$ sulphur in one gramme of the ore.

Iron.

The ferric hydrate, precipitated from the original solution in the sulphur determination, is dissolved in dilute sulphuric acid,

warmed, and reduced with pure zinc until no coloration is produced when a drop of the liquid is brought into contact with a drop of potassium-sulphocyanate solution.

It is then cooled, and titrated with $\frac{1}{5}$ N permanganate solution, until the faintest possible pink color remains constant for two minutes. Every c.c. of the permanganate employed = .0056 Fe in one gramme of the ore.

Copper.

Five grammes of the original sample are treated with concentrated nitric acid, and evaporated to dryness. The residue is treated with concentrated sulphuric acid; heated on a sand-bath till the free acid is all driven off; and then cooled, treated with water, boiled, cooled again, finally treated with one-fourth its volume of alcohol, and allowed to stand for twelve hours and filtered. The residue on the filter is washed three times with a mixture of one part alcohol and two parts water, and the dilute filtrate is then saturated with hydrogen sulphide and allowed to stand for some hours. The precipitated sulphides are washed with a solution of H_2S; dissolved in aqua regia; neutralized with an excess of ammonia; and made slightly acid again with hydrochloric acid. If not clear, the solution is then filtered, and the filter well washed until no longer acid.

The solution is now boiled and treated with 25 c.c. of a strong mixture, containing equal weights of potassium sulphocyanide and sodium bisulphite. The addition is made by degrees and with constant stirring, and, when completed, the beaker is removed from the fire and allowed to stand until quite cold, when the white precipitate of *copper sub-sulphocyanide* will have all gone down. The liquid is now filtered carefully through a double-tared filter, and the precipitate is well washed several times, first by decantation with cold water in the beaker, and finally on the filter. The washing is complete when all traces of chlorides have disappeared, and the precipitate is then thoroughly dried in the gas-oven. When *perfectly dry* it is weighed, the tare of the double filter is deducted from the weight, and the balance $\times .\frac{6320}{5}$ = Cu in one gramme of the ore.

ANALYSIS OF BRIMSTONE.

Moisture.

In order to prevent the evaporation of moisture during grinding, an average sample of the unground or only roughly-crushed material weighing 100 grammes is dried at 100° C. for some hours in an oven or water-bath.

Ashes.

Ten grammes are burnt in a tared porcelain dish and the residue is weighed.

Direct Estimation of Sulphur.

Fifty grammes of the finely-ground brimstone are dissolved in 200 c.c. carbon bisulphide, by digesting it in a stoppered bottle at the ordinary temperature, and the specific gravity of the liquid = s is estimated. This must be reduced to the specific gravity at 15° C. = S by means of the formula (valid up to 25° C.) $S = s + 0.0014 (t-15°)$. The following table gives for each value of S the percentage in this solution, which number must be multiplied by 4 to indicate the percentage of sulphur in the sample of brimstone:

Spec. Grav.	% S.	Spec. Grav.	% S.	Spec. Grav.	% S.	Spec. Grav.	% S.	Spec. Grav.	% S.	Spec. Grav.	% S.
1.271	0	1.292	5.0	1.313	10.2	1.334	15.2	1.355	20.4	1.376	28.1
1.272	0.2	1.293	5 3	1.314	10.4	1.335	15.4	1.356	20.6	1.377	28.5
1.273	0.4	1.294	5.6	1.315	10.6	1.336	15.6	1.357	21.0	1.378	29.0
1.274	0.6	1.295	5.8	1.316	10.9	1.337	15.9	1.358	21.2	1.379	29.7
1.275	0.9	1.296	6.0	1.317	11.1	1.338	16.1	1.359	21.5	1.380	30.2
1.276	1.2	1.297	6.3	1.318	11.3	1.339	16.4	1.360	21.8	1.381	30.8
1.277	1.4	1.298	6.5	1.319	11.6	1.340	16.6	1.361	22.1	1.382	31.4
1.278	1.6	1.299	6.7	1.320	11.8	1.341	16.9	1.362	22.3	1.383	31.9
1.279	1.9	1.300	7.0	1.321	12.1	1.342	17.1	1.363	22.7	1.384	32.6
1.280	2.1	1.301	7.2	1.322	12.3	1.343	17.4	1.364	23.0	1.385	33.2
1.281	2.4	1.302	7.5	1.323	12.6	1.344	17.6	1.365	23.2	1.386	33.8
1.282	2.6	1.303	7.8	1.324	12.8	1.345	17.9	1.366	23.6	1.387	34.5
1.283	2.9	1.304	8.0	1.325	13.1	1.346	18.1	1.367	24.0	1.388	35.2
1.284	3.1	1.305	8.2	1.326	13.3	1.347	18.4	1.368	24.3	1.389	36.1
1.285	3.4	1.306	8.5	1.327	13.5	1.348	18.6	1.369	24.8	1.390	36.7
1.286	3.6	1.307	8.7	1.328	13.8	1.349	18.9	1.370	25.1	1.391	37.2
1.287	3.9	1.308	8.9	1.329	14.0	1.350	19.0	1.371	25.6	(saturated)	
1.288	4.1	1.309	9.2	1.330	14.2	1.351	19.3	1.372	26.0		
1.289	4.4	1.310	9.9	1.331	14.5	1.352	19.6	1.373	26.5		
1.290	4 6	1.311	9.4	1.332	14.7	1.353	19.9	1.374	26.9		
1.291	4.8	1.312	9.7	1.333	15.0	1.354	20.1	1.375	27.4		

ESTIMATION OF SULPHURIC ACID.

According to our experience, the amount of actual H_2SO_4 contained in a given bulk of chamber acid is best determined in the volumetric way as described by Lunge—*i.e.*, by titrating a measured volume of the acid with standard soda solution, using methyl orange as the indicator (31 grammes pure sodium oxide in 1 litre distilled water, standardized with very accurate normal HCl.)

The results are always expressed in percentages of monohydrated sulphuric acid (H_2SO_4) by weight. The specific gravity of the acid is taken with a hydrometer and called x. Ten c.c. of the acid are then taken with an accurate pipette and diluted to 100 c.c. Of this solution 10 c.c. are taken for titration, and, if the number of cubic centimetres of normal soda solution = 0.031 gramme Na_2O per cubic centimetre consumed is called y, the percentage of the acid is $\frac{4.9\ y}{x}$.

RAPID ANALYSIS OF LIMESTONE OR CHALK.

Insoluble.

One gramme of the substance is dissolved in hydrochloric acid and the residue is filtered, washed, dried, and ignited. In the presence of appreciable quantities of organic substance the filter is weighed after drying at 100°, and afterwards ignited. The difference between the first and second weights is taken as organic matter.

Lime.

One gramme of the substance is dissolved in 25 c.c. normal hydrochloric acid and titrated with normal alkali. The amount of alkali used is deducted from 25 and the remainder is multiplied by 2.8 to find the percentage of CaO, or by 5 to find that of $CaCO_3$. If any magnesia be present it would be calculated as lime, and provided its amount be not very large, this is admissible in the manufacture of "supers" on the plan we have suggested.

When, however, the magnesia exceeds, say two per cent., it can be separately estimated as follows, and the result deducted from the figure given above.

Magnesia.

Two grammes of the substance are dissolved in HCl; the CaO is precipitated with NH_3 and ammonium oxalate, and filtered with the usual precautions. The magnesia is precipitated in the filtrate by sodium phosphate, filtered, washed with ammonia water, dried, ignited, and weighed as $Mg_2P_2O_7$, which × .3603 = MgO.

Iron.

Two grammes of the substance are dissolved in HCl, reduced by zinc, and diluted. Some manganese solution free from iron is then added and the mixture is titrated with $\frac{1}{5}$ N. permanganate, of which each c.c. = .0080 Fe_2O_3.

TABLE GIVING THE ATOMIC WEIGHT OF THE ELEMENTS ACCORDING TO THE LATEST DETERMINATIONS.

Name.	Atomic Weight.	Name.	Atomic Weight.
Aluminum	27.3	Molybdenum	95.6
Antimony	122.0	Nickel	58.6
Arsenic	74.9	Niobium	94.0
Barium	136.8	Nitrogen	14.01
Beryllium	9.0	Osmium	198.6
Bismuth	210.0	Oxygen	15.96
Boron	11.0	Palladium	106.2
Bromine	79.75	Phosphorus	30.96
Cadmium	111.6	Platinum	196.7
Cæsium	133.0	Potassium	39.04
Calcium	39.9	Rhodium	104.1
Carbon	11.97	Rubidium	85.2
Chlorine	35.37	Ruthenium	103.5
Cerium	141.2	Selenium	78.0
Chromium	52.4	Silicon	28.0
Cobalt	58.6	Silver	107.66
Copper	63.0	Sodium	22.96
Didymium	147.0	Strontium	87.2
Erbium	169.0	Sulphur	31.98
Fluorine	19.1	Tantalum	182.0
Gold	196.2	Tellurium	128.0
Hydrogen	1.0	Thallium	203.6
Indium	113.4	Thorium	231.5
Iodine	126.53	Tin	117.8
Iridium	196.7	Titanium	48.0
Iron	55.9	Tungsten	184.0
Lanthanum	139.0	Uranium	240.0
Lead	206.4	Vanadium	51.2
Lithium	7.01	Yttrium	93.0
Magnesium	23.94	Zinc	64.9
Manganese	54.8	Zirconium	90.0
Mercury	199.8		

WEIGHTS AND MEASURES OF THE METRICAL SYSTEM.

Weights.

1 milligramme = .001 gramme.
1 centigramme = .01 gramme.
1 decigramme = .1 gramme.
1 gramme = weight of a cubic centimetre of water at 4° C.
1 decagramme = 10.000 grammes.
1 hectogramme = 100.000 grammes.
1 kilogramme = 1000.000 grammes.

Measures of Capacity.

1 millilitre = 1 cubic centimetre, or the measure of 1 gramme of water.
1 centilitre = 10 cubic cent.
1 decilitre = 100 cubic cent.
1 litre = 1000 cubic cent.

Measures of Length.

1 millimetre = .001 metre.
1 centimetre = .01 metre.
1 decimetre = .1 metre.
1 metre = the ten-millionth part of a quarter of the earth's meridian.

STOCHIOMETRY, OR CHEMICAL CALCULATIONS.

Conversion of Thermometer Degrees.

°C. to °R., multiply by 4 and divide by 5.
°C. to °F., multiply by 9, divide by 5, then add 32.
°R. to °C., multiply by 5 and divide by 4.
°R. to °F., multiply by 9, divide by 4, then add 32.
°F. to °R., first subtract 32, then multiply by 4 and divide by 9.
°F. to °C., first subtract 32, then multiply by 5 and divide by 9.

To Find the Percentage Composition having the Formula Given.

Find the molecular weight from the formula, then

$$\frac{\text{Molecular weight}}{100} = \frac{\text{Weight of constituent in a molecule.}}{\text{Percentage of constituent.}}$$

Or, proceed thus:

Multiply the atomic weight of the element by 1, 2, 3, etc., according to the number of atoms of the element there are in the molecule; multiply the number thus obtained by 100 and divide by the molecular weight.

To Find the Weight of any Element Contained in any Given Weight of a Compound Substance.

$$\frac{\text{Molecular weight}}{\text{Given weight}} = \frac{\text{Weight of constituent in a molecule.}}{\text{Required weight.}}$$

Or, multiply the atomic weight of the element by 1, 2, 3, etc., according to the number of atoms of the element there are in the molecule; multiply the number thus obtained by the given weight and divide by the molecular weight.

DETERMINATION OF THE SPECIFIC GRAVITY OF SOLIDS.

Solids heavier than, and insoluble in, water.

a. By weighing in air and water.

$$\text{Sp. gr.} = \frac{\text{(weight in air)}}{\text{(loss of weight in water)}}.$$

b. By Nicholson's hydrometer.

Let w_1 be the weight required to sink the instrument to the mark on the stem, the weight of the instrument being W; to take the specific gravity of any solid substance, place a portion of it weighing less than w_1 in the upper pan, with such additional weight, say w_3, as will cause the instrument to sink to the zero-mark. The weight of the substance is then $w_1 - w_3$. Next transfer the substance to the lower pan, and again adjust with weight w_4 to the zero-mark.

$$\text{Sp. gr.} = \frac{w_1 - w_3}{w_4 - w_2}.$$

c. By the specific-gravity bottle (applicable to powders).

Weigh the flask filled to the mark with water, then place the substance, of known weight in the flask, fill to the mark with water and weigh again.

$$\text{Sp. gr.} = \frac{\text{(weight of substance in air)} + \text{(weight of flask and water)} - \text{(weight of flask and water and substance)}}{\text{(weight of substance in air)}}.$$

Solids lighter than, and insoluble in, water.

The solid is weighted by a piece of lead of known specific gravity and weighed in water.

$$\text{Sp. gr.} = \frac{\text{(weight of substance in air)}}{\text{(weight of lead in water)} - \text{(weight of lead and substance in water)} + \text{(weight of substance in air)}}.$$

Solids heavier than, and insoluble in, water.

Proceed as in *a*, using instead of water some liquid without action on the solid.

(weight of bulk of liquid equal to substance) =
(weight of substance in air) — (weight of substance in liquid).

$$\text{(weight of bulk of water equal to substance)} = \frac{\text{(weight of bulk of liquid equal to substance)} \times \text{(sp. gr. of water)}}{\text{(sp. gr. of liquid)}}.$$

$$\text{Sp. gr.} = \frac{\text{(weight of substance in air)}}{\text{(weight of bulk of water equal to substance)}}.$$

NOTES ON STANDARD ACID, ALKALINE, AND OTHER SOLUTIONS, CALLED FOR IN THIS WORK.

In the conduct of volumetric examinations, which are frequently extremely useful, expeditious and exact, it is essential that all "standard" solutions be prepared and employed as nearly as possible at a constant temperature. This temperature should be that of the surrounding atmosphere, or as cool a place as may be available in the laboratory, say 60° to 70° F. The liquids should be kept as clear as possible, and always shaken up just previous to being used.

The *indicator* most commonly used in alkalimetry and acidimetry is tincture of litmus, which must be kept in open vessels, to avoid its being spoiled. When employing litmus, the liquid to be tested must be kept boiling for some time, in order to expel all CO_2; and normal acid must be added as long as further boiling causes the color to change back from red to purple or blue. This takes a long time; sometimes half an hour or even more. This time may be saved by replacing litmus by a very dilute solution of methyl-orange (sulphobenzene-azodimethyl-aniline); but in this case the liquids must never be hot, but of the ordinary temperature, and none but mineral acids may be employed. The cold solution of sodium carbonate is colored just perceptibly yellow by adding a drop or two of the solution of methyl-orange, preferably by means of a pipette; if the color is too intense, it will on neutralization cause the transition into red to be less sharp. Methyl-orange is not acted upon in the least by CO_2, and when all Na_2CO_3 has been decomposed, the slightest excess of HCl causes the yellow to change suddenly and sharply into pink. The rule is, therefore, to run in the normal acid quickly and with constant agitation till the change of color has taken place. The opposite change of color from pink to faint yellow is just as sharp when titrating mineral acids with sodium hydrate or carbonate. The results are identical with those obtained by litmus, but, as we have said, they are obtained very much more quickly, and without heating the liquids.

Other indicators in constant use are phenolphthalein and coralline, of which it is always useful to have a small supply.

NORMAL SODIUM CARBONATE.

Dissolve 53 grammes of pure, dry monocarbonate, prepared by

gniting the bicarbonate to redness, in water, and make up to one litre.

NORMAL SULPHURIC ACID.

Dilute about 30 c.c. of pure sulphuric acid (sp. gr. 1.840) to one litre; then determine the strength of this solution by titration with normal sodium carbonate, and dilute so as to make one c.c. of the sulphuric acid neutralize one c.c. of the alkali; after dilution check the strength by another titration.

DECI-NORMAL OXALIC ACID.

Dissolve 6.3 grammes of pure, recrystallized oxalic acid, dried between paper, in one litre of water.

NORMAL HYDROCHLORIC ACID.

Dilute 181 grammes of the pure acid, of sp. gr. 1.10, to one litre; check by titration with $\frac{N}{10}$ silver solution or by sodium carbonate.

NORMAL NITRIC ACID.

Take some pure nitric acid and dilute to one litre. The strength of this solution must be ascertained, and the acid diluted accordingly. The most exact method of checking the nitric acid is by pure calcium carbonate, one gramme of which requires 20 c.c. of normal acid.

NORMAL CAUSTIC ALKALI.

Take about 42 grammes of *pure* sodium hydrate and dissolve in 800 c.c. of water; titrate with any normal acid, and dilute until it corresponds with the acid, volume for volume. NORMAL POTASSIUM HYDRATE may be made in a similar manner.

NORMAL AMMONIUM HYDRATE

is made by diluting strong ammonia to the required strength, and checking by titration with normal acid.

DECI-NORMAL SILVER NITRATE SOLUTION.

Dissolve 10.8 grammes of pure silver in pure dilute nitric acid, heat gently, and when dissolved dilute to one litre. If a neutral solution is required, take 17 grammes of pure silver nitrate and dissolve in water to one litre. Of this solution

1 c.c. = .01080 gramme Ag.
" = .01700 " $AgNo_3$.
" = .00355 " Cl.
" = .00585 " NaCl.

DECI-NORMAL SODIUM CHLORIDE SOLUTION.

Dissolve 5.85 grammes of pure sodium chloride, dried by gentle ignition, to one litre.

1 c.c. = .00585 gramme NaCl.
" = .00355 " Cl.
" = .01080 " Ag.

BARIUM CHLORIDE SOLUTION.

Dissolve 122 grammes of barium chloride, dried between paper to one litre.

1 c.c. = .0490 gramme H_2SO_4.
" = .0480 " SO_4.
" = .0400 " SO_3.
" = .1220 " $BaCl_2(2H_2O)$.
" = .1040 " $BaCl_2$.
" = .0685 " Ba.

STANDARD URANIUM SOLUTION.

Take about 40 grammes of uranium acetate, dissolve in water; add about 25 c.c. of glacial acetic acid, and make up to one litre. This solution is then titrated against the sodium phosphate and diluted until 50 c.c. are equivalent to 50 c.c. of the latter.

1 c.c. = .002 gramme P_2O_5.

STANDARD SODIUM PHOSPHATE SOLUTION.

Take 10.085 grammes of pure, crystallized, non-effloresced, disodium hydrogen phosphate, dried between paper, and dissolve to one litre. Check this solution by evaporating 50 c.c. to dryness and igniting. The residue should weigh .1874 gramme.

50 c.c. = .1 gramme P_2O_5.

SODIUM ACETATE SOLUTION.

Dissolve 100 grammes of the salt in water, add 100 cc. of pure acetic acid (sp. gr. 1.04), and dilute to one litre. Exact quantities are not necessary.

MAGNESIA MIXTURE.

Dissolve 110 grammes of dry crystallized magnesium chloride and 280 grammes of ammonium chloride in one litre of distilled water. Filter, add 700 c.c. liquor of ammonia of specific gravity .96 and shake. Allow to cool and then add sufficient distilled water to complete two litres, mix thoroughly and label.

NEUTRAL AMMONIUM CITRATE SOLUTION.

Mix 370 grammes of commercial citric acid with 1500 cubic centimetres of water; nearly neutralize with crushed commercial carbonate of ammonia; heat to expel the carbonic acid; cool; add ammonia until exactly neutral (testing by saturated alcoholic solution of coralline) and bring to a volume of two litres. Test the gravity, which should be 1.09 at 20° C., before using.

AMMONIUM NITRATE SOLUTION.

Dissolve 200 grammes of commercial ammonium nitrate in water and bring to a volume of two litres.

MOLYBDIC SOLUTION.

Dissolve 150 grammes of ammonium molybdate in one litre of distilled water. Pour the solution slowly and in small portions at a time into one litre of nitric acid of specific gravity 1.20. After each addition of the ammonium molybdate solution the mixture must be shaken and the agitation kept up until the liquid is entirely clear.

Keep the mixture in a warm place for several days, or until a portion heated to 40° C. deposits no yellow precipitate of ammonium phospho-molybdate. Decant the solution from any sediment, and preserve in glass-stoppered vessels.

Fifty c.c. of this solution suffice to precipitate 0.100 gramme P_2O_5.

SATURATED SOLUTION OF AMMONIUM OXALATE.

Place about eight ounces of pure ammonium oxalate in a litre bottle, fill up with pure distilled water, shake occasionally during a few hours, finally allow to settle and use the supernatant liquid, drawing it off with a pipette as required.

STANDARD POTASSIUM PERMANGANATE SOLUTION.

For the accurate determination of iron in small quantities we prefer the permanganate to any other reagent. The iron is re-

duced to the *ferrous* state and the permanganate solution is then added until all the iron is *peroxidized*, a fact which is demonstrated directly the color of the iron solution turns purple. The quantity of permanganate used in the operation is the measure of the iron present, as may be gathered from the equation :

$$10FeSO_4+8H_2SO_4+2KMnO_4=5Fe_2(SO_4)_3+K_2SO_4+2MnSO_4+8H_2O.$$

The solution may be conveniently made of quinquenormal strength. Dissolve 3.162 grammes of very dry permanganate of potassium in one litre of water and keep in a stoppered bottle. Every c.c. of the solution should be equal to .0056 Fe or .0080 Fe_2O_3.

To ascertain its exact strength, which is a very important point considering the small amounts of iron we are generally called upon to determine, dissolve one gramme of double sulphate of iron and ammonium in 20 c.c. of water and 5 c.c. dilute sulphuric acid. If 25 c.c. of the permanganate are required to produce a faint pink color, permanent for two minutes, the solution is sufficiently correct. One hundred c.c. of this solution may be diluted to one litre with distilled water and labelled $\frac{1}{50}$ N. permanganate solution, every c.c. of which = .00080 ferric oxide.

SYMBOLS, MOLECULAR WEIGHTS, AND PERCENTAGE COMPOSITION, OF SUBSTANCES USED IN THE FERTILIZER INDUSTRY.

Substance.	Molecular Formula	Molecular Weight	Percentage Composition.
Aluminum oxide.....	Al_2O_3	103	Al 53.40, O 46.60.
" hydrate....	$Al_2(HO)_6$	157	Al_2O_3 65.61, H_2O 34.39.
Ammonia.....	NH_3	17	N 82.35, H 17.67.
Ammonium carbonate.	$H(NH_4)Co_3$ + $(NH_4)CO_2NH_2$.	157	NH_3 32.49, CO_2 56.05, H_2O 11.46.
" chloride...	NH_4Cl.....	53.5	NH_3 31.77, HCl 68.23.
" magnesium phosphate cryst.....	$Mg(NH_4)PO_4$+ 6aq	245	MgO 16.30, NH_3 6.93, P_2O_5 29.09, H_2O 47.68.
" nitrate.....	NH_4NO_3.....	80	NH_3 21.25, N_2O_5 67.50, H_2O 11.25.
" phosphate.	$(NH_4)_2HPO_4$..	132	NH_3 25.68, P_2O_5 53.93, H_2O 20.39.
" sod'm phosphate.....	$(NH_4)NaHPO_4$ + 4aq.....	209	NH_3 8.13, Na_2O 14.83, P_2O_5 33.97, H_2O 43.06.

Symbols, Molecular Weights, and Percentage Composition, of Substances used in the Fertilizer Industry.—*Continued.*

Substance.	Molecular Formula.	Molecular Weight	Percentage Composition.
Barium chloride	$BaCl_2 + 2aq$	244	$BaCl_2$ 85.24, H_2O 14.76.
" sulphate	$BaSO_4$	233	BaO 65.67, SO_3 34.33.
Calcium monoxide	CaO	56	Ca 71.43, O 28.57.
" hydrate	$Ca(HO)_2$	74	CaO 75.67, H_2O 24.33.
" carbonate	$CaCO_3$	100	CaO 56.00, CO_2 44.00.
" chloride	$CaCl_2$	111	Ca 36.05, Cl 63.95.
" chloride cryst.	$CaCl_2 + 6aq$	219	$CaCl_2$ 50.69, H_2O 49.31.
" phosphate monobasic	$CaH_4(PO_4)_2$	234	CaO 23.93, P_2O_5 60.68, H_2O 15.38.
" phosphate, dibasic	$CaHPO_4$	136	CaO 41.18, P_2O_5 52.20, H_2O 6.62.
" phosphate, tribasic	$Ca_3(PO_4)_2$	310	CaO 54.19, P_2O_5 45.81.
" sulphate, anhydrous	$CaSO_4$	136	CaO 41.18, SO_3 58.82.
" sulphate, cryst (gypsum)	$CaSO_4 + 2aq$	172	CaO 32.56, SO_3 46.51, H_2O 20.93.
Carbonic anhydride	CO_2	44	C 27.27, O 72.73.
" oxide	CO	28	C 42.85, O 57.15.
Hydrochloric acid	HCl	36.5	Cl 97.26, H 2.74.
Iron oxide	Fe_2O_3	160	Fe 70.00, O 30.00.
Magnesium chloride	$MgCl_2$	95	Mg 25.26, Cl 74.74.
" chloride crystals	$MgCl_2 + 6aq$	203	$MgCl_2$ 46.80, H_2O 53.20.
" carbonate	$MgCO^3$	84	MgO 46.62, CO^2 53.38.
" sulphate	$MgSO_4 + 7aq$	246	MgO 16.26, SO_3 32.52, H_2O 51.22.
" pyrophosphate	$Mg_2P_2O_7$	222	MgO 36.04, P_2O_5 63.96.
Nitric acid	HNO_3	63	N_2O_5 85.71, H_2O 14.29.
Phosphoric anhydride	P_2O_5	142	P 43.66, O 56.34.
" acid	H_3PO_4	98	P_2O_5 72.45, H_2O 27.55.
Potassium permanganate	$KMnO_4$	158	K_2O 29.75, Mn_2O_7 70.25.
Silicic acid	SiO_2	60	Si 46.67, O 53.33.
Sodium hydrate	NaHO	40	Na_2O 77.50, H_2O 22.50.
" carbonate	Na_2CO_3	106	Na_2O 58.49, CO_2 41.51.
" bicarbonate	$NaHCO_3$	84	Na_2O 36.90, CO^2 52.38, H_2O 10.71.
" phosphate	$Na_2HPO_4 + 12aq$	358	Na_2O 17.32, P_2O_5 19.84, H_2O 62.84.
Sulphurous anhydride	SO_2	64	S 50.00, O 50.00.
Sulphuric anhydride	SO_3	80	S 40.00, O 60.00.
" acid (monohydrate)	H_2SO_4	98	SO_3 81.63, H_2O 18.37.
Pyro-sulphuric acid	$H_2S_2O_7$	178	H_2SO_4 55.06, SO_3 44.94.
Thio-sulphuric "	$H_2S_2O_3$	114	SO_2 56.14, S 28.07, H_2O 15.79.
Water	H_2O	18	H 11.11, O 88.89.

USEFUL TABLES FOR THE FACTORY.

TABLE FOR THE SYSTEMATIC ANALYSIS OF ALKALIES, ALKALINE EARTHS AND ACIDS.

Substance.	Formula.	Molecular Weight.	Quantity to be weighed so that 1 c.c. of Normal Solution = 1 per cent. of Substance.	Normal Factor.
			Grammes.	
Sodium oxide	Na_2O	62	3.1	.031
" hydrate	$NaHO$	40	4.0	.040
" carbonate	Na_2CO_3	106	5.3	.053
" bicarbonate	$NaHCO_3$	84	8.4	.084
Potassium oxide	K_2O	94	4.7	.047
" hydrate	KHO	56	5.6	.056
" carbonate	K_2CO_3	138	6.9	.069
" bicarbonate	$KHCO_3$	100	10.0	.100
Ammonia	NH_3	17	1.7	.017
Ammonium carbonate	$(NH_4)_2CO_3$	96	4.8	.048
Calcium oxide (lime)	CaO	56	2.8	.028
" hydrate	CaH_2O_2	74	3.7	.037
" carbonate	$CaCO_3$	100	5.0	.050
Barium hydrate	BaH_2O_2	171	8.55	.0855
" " (cry.)	$BaH_2O_28H_2O$	315	15.75	.1575
" carbonate	$BaCO_3$	197	9.85	.0985
Strontium oxide	SrO	103.5	5.175	.0575
" carbonate	$SrCO_3$	147.5	7.375	.07375
Magnesium oxide	MgO	40	2.00	.020
" carbonate	$MgCO_3$	84	4.20	.042
Nitric acid	HNO_3	63	6.3	.063
Hydrochloric acid	HCl	36.5	3.65	.0365
Sulphuric acid	H_2SO_4	98	4.9	.049
Oxalic acid	$H_2C_2O_4$	126	6.3	.063
Acetic acid	$H_4C_2O_2$	60	6.0	.060
Tartaric acid	$H_6C_4O_6$	150	7.5	.075
Citric acid	$C_6O_7H_8+H_2O$	210	7.0	.070

In order to find the amount of pure substance present in the material examined multiply the number of c.c. by the "normal factor."

TABLE COMPARING THE DEGREES OF BAUME WITH SPECIFIC GRAVITY DEGREES AT 15° C.

Degs. of Baumé.	Sp. Gr.	Degs. of Baumé.	Sp. Gr.	Degs. of Baumé.	Sp. Gr.	Degs. of Baumé.	Sp. Gr.
0	1.000	19	1.147	37	1.337	55	1.596
1	1.007	20	1.157	38	1.349	56	1.615
2	1.014	21	1.166	39	1.361	57	1.634
3	1.020	22	1.176	40	1.375	58	1.653
4	1.028	23	1.185	41	1.388	59	1.671
5	1.031	24	1.195	42	1.401	60	1.690
6	1.041	25	1.205	43	1.414	61	1.709
7	1.049	26	1.215	44	1.428	62	1.729
8	1.057	27	1.225	45	1.442	63	1.750
9	1.064	28	1.234	46	1.456	64	1.771
10	1.072	29	1.245	47	1.470	65	1.793
11	1.080	30	1.256	48	1.485	66	1.815
12	1.088	31	1.267	49	1.500	67	1.839
13	1.096	32	1.278	50	1.515	68	1.864
14	1.104	33	1.289	51	1.531	69	1.885
15	1.113	34	1.300	52	1.546	70	1.909
16	1.121	35	1.312	53	1.562	71	1.935
17	1.130	36	1.324	54	1.578	72	1.960
18	1.138						

ANTHON'S TABLE BY WHICH TO PREPARE SULPHURIC ACID (OIL OF VITRIOL) OF ANY STRENGTH BY MIXING THE ACID OF 1.86 SPECIFIC GRAVITY WITH WATER.

100 parts of Water at 15° to 20° being mixed with parts of Sulphuric Acid of 1.86 sp. gr.	Give an Acid of Specific Gravity.	100 parts of Water at 15° to 20° being mixed with parts of Sulphuric Acid of 1.86 sp. gr.	Give an Acid of Specific Gravity.	100 parts of Water at 15° to 20° being mixed with parts of Sulphuric Acid of 1.86 sp. gr.	Give an Acid of Specific Gravity.
1	1.009	130	1.456	370	1.723
2	1.015	140	1.473	380	1.727
5	1.035	150	1.490	390	1.730
10	1.060	160	1.510	400	1.733
15	1.090	170	1.530	410	1.737
20	1.113	180	1.543	420	1.740
25	1.140	190	1.456	430	1.743
30	1.165	200	1.568	440	1.746
35	1.187	210	1.580	450	1.750
40	1.210	220	1.593	460	1.754
45	1.229	230	1.606	470	1.757
50	1.248	240	1.620	480	1.760
55	1.265	250	1.630	490	1.763
60	1.280	260	1.640	500	1.766
65	1.297	270	1.648	510	1.768
70	1.312	280	1.654	520	1.770
75	1.326	290	1.667	530	1.772
80	1.340	300	1.678	540	1.774
85	1.357	310	1.689	550	1.776
90	1.372	320	1.700	560	1.777
95	1.386	330	1.705	580	1.778
100	1.398	340	1.710	590	1.780
110	1.420	350	1.714	600	1.782
120	1.438	360	1.719		

TABLE SHOWING THE STRENGTH OF SOLUTIONS OF PHOSPHORIC ACID BY SPECIFIC GRAVITY AT 15° C.

Specific Gravity.	Per cent. of H_3PO_4.	Per cent. of P_2O_5.	Specific Gravity.	Per cent. of H_3PO_4.	Per cent. of P_2O_5.
1.0054	1	.726	1.1962	31	22.506
1.0109	2	1.452	1.2066	32	23.232
1.0164	3	2.178	1.2111	33	23.958
1.0220	4	2.904	1.2186	34	24.684
1.0276	5	3.630	1.2262	35	25.410
1.0333	6	4.356	1.2338	36	26.136
1.0390	7	5.082	1.2415	37	26.862
1.0449	8	5.808	1.2493	38	27.588
1.0508	9	6.534	1.2572	39	28.314
1.0567	10	7.260	1.2651	40	29.040
1.0627	11	7.986	1.2731	41	29.766
1.0688	12	8.712	1.2812	42	30.492
1.0749	13	9.438	1.2894	43	31.218
1.0811	14	10.164	1.2976	44	31.944
1.0874	15	10.890	1.3059	45	32.670
1.0937	16	11.616	1.3143	46	33.396
1.1001	17	12.342	1.3227	47	34.222
1.1065	18	13.068	1.3313	48	34.948
1.1130	19	13.794	1.3399	49	35.674
1.1196	20	14.520	1.3486	50	36.400
1.1262	21	15.246	1.3573	51	37.126
1.1329	22	15.972	1.3661	52	37.852
1.1397	23	16.698	1.3750	53	38.578
1.1465	24	17.424	1.3840	54	39.304
1.1534	25	18.150	1.3931	55	40.030
1.1604	26	18.876	1.4022	56	40.756
1.1674	27	19.602	1.4114	57	41.482
1.1745	28	20.328	1.4207	58	42.208
1.1817	29	21.054	1.4301	59	42.934
1.1889	30	21.780	1.4395	60	43.660

URE'S TABLE SHOWING THE STRENGTH OF SOLUTIONS OF AMMONIA.

Specific Gravity.	Per cent. of Ammonia.	Specific Gravity.	Per cent. of Ammonia.	Specific Gravity.	Per cent. of Ammonia.
.8914	27.940	.9177	21.200	.9564	10.600
.8937	27.633	.9227	19.875	.9614	9.275
.8967	27.038	.9275	18.550	.9662	7.950
.8983	26.751	.9320	17.225	.9716	6.625
.9000	26.500	.9363	15.900	.9768	5.300
.9045	25.175	.9410	14.575	.9828	3.975
.9090	23.850	.9455	13.250	.9887	2.650
.9133	22.525	.9510	11.925	.9945	1.325

TABLE SHOWING THE STRENGTH OF SOLUTIONS OF BARIUM CHLORIDE BY SPECIFIC GRAVITY AT 21.5° C.

Specific Gravity.	Per cent. of $BaCl_2 + 2Aq.$	Per cent. of $BaCl_2$.	Specific Gravity.	Per cent. of $BaCl_2 + 2Aq.$	Per cent. of $BaCl_2$.
1.0073	1	.853	1.1302	16	13.641
1.0147	2	1.705	1.1394	17	14.494
1.0222	3	2.558	1.1488	18	15.346
1.0298	4	3.410	1.1584	19	16.199
1.0374	5	4.263	1.1683	20	17.051
1.0452	6	5.115	1.1783	21	17.904
1.0530	7	5.968	1.1884	22	18.756
1.0610	8	6.821	1.1986	23	19.609
1.0692	9	7.673	1.2090	24	20.461
1.0776	10	8.526	1.2197	25	21.314
1.0861	11	9.379	1.2304	26	22.166
1.0947	12	10.231	1.2413	27	23.019
1.1034	13	11.084	1.2523	28	23.871
1.1122	14	11.936	1.2636	29	24.724
1.1211	15	12.789	1.2750	30	25.577

TABLES SHOWING THE SPECIFIC GRAVITY AND PERCENTAGE OF SOME SATURATED SOLUTIONS USED IN FERTILIZER ANALYSIS, ETC.

The Percentage refers to Anhydrous Salt.

	Temperature. *Celsius.*	Percentage of Salt.	Specific Gravity.
Ammonium chloride	15	26.30	1.0776
" sulphate	19	50.00	1.2890
Barium chloride	15	25.97	1.2827
Calcium chloride	15	40.66	1.4110
Magnesium sulphate	15	25.25	1.2880

TABLE SHOWING THE STRENGTH OF SOLUTIONS OF NITRIC ACID BY SPECIFIC GRAVITY AT 15° C.

Specific Gravity.	Liquid Acid (sp.gr. 1.5) in 100 pts	Dry Acid in 100 parts	Specific Gravity.	Liquid Acid (sp.gr. 1.5) in 100 pts	Dry Acid in 100 parts	Specific Gravity.	Liquid Acid (sp.gr. 1.5) in 100 pts	Dry Acid in 100 parts	Specific Gravity.	Liquid Acid (sp.gr. 1.5) in 100 pts	Dry Acid in 100 parts
1.5000	100	79.700	1.4189	75	59.775	1.2947	50	39.850	1.1403	25	19.925
1.4980	99	78.903	1.4147	74	58.978	1.2887	49	39.053	1.1345	24	19.128
1.4960	98	78.106	1.4107	73	58.181	1.2826	48	38.256	1.1286	23	18.331
1.4940	97	77.309	1.4065	72	57.384	1.2765	47	37.459	1.1227	22	17.534
1.4910	96	76.512	1.4023	71	56.557	1.2705	46	36.662	1.1168	21	16.737
1.4880	95	75.715	1.3978	70	55.790	1.2644	45	35.865	1.1109	20	15.940
1.4850	94	74.918	1.3945	69	54.993	1.2583	44	35.068	1.1051	19	15.143
1.4820	93	74.121	1.3882	68	54.196	1.2523	43	34.271	1.0993	18	14.346
1.4790	92	73.324	1.3833	67	53.339	1.2462	42	33.474	1.0935	17	13.549
1.4760	91	72.527	1.3783	66	52.602	1.2402	41	32.677	1.0878	16	12.752
1.4730	90	71.730	1.3732	65	51.805	1.2341	40	31.880	1.0821	15	11.955
1.4700	89	70.933	1.3681	64	51.068	1.2277	39	31.083	1.0764	14	11.158
1.4670	88	70.136	1.3630	63	50.211	1.2212	38	30.286	1.0708	13	10.868
1.4640	87	69.339	1.3579	62	49.414	1.2148	37	29.489	1.0651	12	9.564
1.4600	86	68.542	1.3529	61	48.617	1.2084	36	28.692	1.0595	11	8.767
1.4570	85	67.745	1.3477	60	47.820	1.2019	35	27.895	1.0540	10	7.970
1.4530	84	66.948	1.3427	59	47.023	1.1958	34	27.098	1.0485	9	7.173
1.4500	83	66.155	1.3376	58	46.226	1.1895	33	26.301	1.0430	8	6.376
1.4460	82	65.354	1.3323	57	45.429	1.1833	32	25.504	1.9375	7	5.579
1.4424	81	64.557	1.3270	56	44.632	1.1770	31	24.707	1.0320	6	4.782
1.4385	80	63.760	1.3216	55	43.836	1.1709	30	23.900	1.0267	5	3.985
1.4346	79	62.963	1.3163	54	43.038	1.1648	29	23.113	1.0212	4	3.138
1.4306	78	62.166	1.3110	53	42.241	1.1587	28	22.316	1.0159	3	2.391
1.4269	77	61.369	1.3056	52	41.444	1.1515	27	21.517	1.0106	2	1.594
1.4228	76	60.572	1.3001	51	40.647	1.1467	26	20.722	1.0053	1	0.797

TABLE SHOWING THE STRENGTH OF HYDROCHLORIC ACID BY SPECIFIC GRAVITY AT 15° C.

Specific Gravity.	Per cent. of HCl.	Per cent. of acid of 1.20 sp. gr.	Specific Gravity.	Per cent. of HCl.	Per cent. of acid of 1.20 sp. gr.	Specific Gravity.	Per cent. of HCl	Per cent. of acid of 1.20 sp. gr.	Specific Gravity.	Per cent. of HCl	Per cent. of acid of 1.20 sp. gr.
1.2000	40.777	100	1.1515	30.582	75	1.1000	20.388	50	1.0497	10.194	25
1.1982	40.369	99	1.1494	30.174	74	1.0980	19.980	49	1.0477	9.786	24
1.1964	39.961	98	1.1473	29.767	73	1.0960	19.572	48	1.0457	9.379	23
1.1946	39.554	97	1.1452	29.359	72	1.0939	19.165	47	1.0437	8.971	22
1.1928	39.146	96	1.1431	28.951	71	1.0919	18.757	46	1.0417	8.563	21
1.1910	38.738	95	1.1410	28.544	70	1.0899	18.349	45	1.0397	8.155	20
1.1893	38.330	94	1.1389	28.136	69	1.0879	17.941	44	1.0377	7.747	19
1.1875	37.923	93	1.1369	27.728	68	1.0859	17.534	43	1.0357	7.340	18
1.1857	37.516	92	1.1349	27.321	67	1.0838	17.126	42	1.0337	6.932	17
1.1846	37.108	91	1.1328	26.913	66	1.0818	16.718	41	1.0318	6.524	16
1.1822	36.700	90	1.1308	26.505	65	1.0798	16.310	40	1.0298	6.116	15
1 1802	36.292	89	1.1287	26.098	64	1.0778	15.902	39	1.0279	5.709	14
1 1782	35.884	88	1.1267	25.690	63	1.0758	15.494	38	1.0259	5.301	13
1.1762	35.476	87	1 1247	25.282	62	1.0738	15.087	37	1.0239	4.893	12
1.1741	35.068	86	1.1226	24.847	61	1.0718	14.679	36	1.0220	4.486	11
1.1721	34.660	85	1.1206	24.466	60	1.0697	14.271	35	1.0200	4.078	10
1.1701	34.252	84	1.1185	24.058	59	1.0677	13.863	34	1.0180	3.670	9
1.1681	33.845	83	1.1164	23.650	58	1.0657	13.456	33	1.0160	3.262	8
1.1661	33.437	82	1.1143	23.242	57	1.0637	13.049	32	1.0140	2.854	7
1.1641	33.029	81	1.1123	22.834	56	1.0617	12.641	31	1.0120	2.447	6
1.16 0	32.621	80	1.1102	22.426	55	1.0597	12.233	30	1 0100	2.039	5
1.1599	32.213	79	1.1082	22.019	54	1.0577	11.825	29	1.0080	1.631	4
1.1578	31.805	78	1.1061	21.611	53	1.0557	11.418	28	1.0060	1.224	3
1.1557	31.398	77	1.1041	21.203	52	1.0537	11.010	27	1.0040	.816	2
1.1536	30.990	76	1.1020	20.796	51	1.517	10.602	26	1.0020	.408	1

TABLE SHOWING THE PRINCIPAL APPARATUS AND CHEMICALS COMPRISING THE "OUTFIT" REQUIRED IN "PHOSPHATE MINING" OR "FERTILIZER FACTORY" LABORATORIES.

1 sand-bath.
1 set fine sieves.
1 iron mortar with pestle.
Porcelain evaporating-dishes.
Hydrometer for light liquids.
Hydrometer for heavy liquids.
Mohr's burette with pinch-cock, 50 c.c. in $\frac{1}{10}$.
Mohr's burette with pinch-cock, 100 c.c. in $\frac{1}{5}$.
Iron support for two burettes.
10-inch lipped cylinders.
Graduated cylinders, 100 c.c.
Iron wire triangles.
Pieces brass wire gauze, 6 x 6.
Iron tripods.
Test-tubes, 5 and 6 inches.
Test-tube stands.
Desiccators.
Triangular files.
Round files.
Funnel supports, wood, for four funnels.
Retort stands, iron, 3 rings.
Quire filter-paper.
24 4-ounce German tincture bottles.
12 16-ounce German tincture bottles.
German glass tubing.
Dozen glass stirrers.
Horn spoons with spatulas.
Rubber tubing for connections.
Flasks, 2, 4, 6, 8, 12, 16 ounces.
1 carbonic-acid apparatus, Schrötter.
Liebig's condenser, 20 inches.
Condenser support.
Gay-Lussac's burette, 50 c.c. in $\frac{1}{10}$.
Burette floats to fit Mohr's burettes.
4 pipettes, volumetric, fixed, 10, 25, 50, 100 c.c.
4 pipettes, Mohr's graduated.

5 10 50 100 c.c.
— — — —
divided in $\frac{1}{20}$ $\frac{1}{10}$ $\frac{1}{10}$ $\frac{1}{5}$

1 Taylor's hand ore-crusher.
Half-dozen boxes gummed labels, assorted sizes.
Several packages of Schleicher and Schuell's washed and cut filters, 7, 9 and 11 centimetres diameter.
1 large Fletcher's blowpipe.
1 dozen rubber tips for glass rods.
1 steel forceps, $4\frac{1}{2}$ inches.
1 air-bath, copper, 6 x 8 inches.
10 grammes platinum foil.
1 yard platinum wire.
1 gross each wide-mouthed bottles, with corks, 1, 2, 4 ounces.
Porcelain mortars, 5 inches, with pestle.
1 pair paper-scissors.
1 dozen royal Berlin crucibles, Nos. 00 and 0, and covers.
1 30-c.c. platinum crucible.
1 100-c.c. platinum dish.
Wash-bottles (pints).
1 chemical balance (for rough weighing), capacity 5 ounces.
1 set weights, 100 grammes down.
2 paper scale thermometers, 100° and 200° C.
Half-dozen each funnels, 2, $2\frac{1}{2}$, 3, 4, 5, 6 inches.
2 dozen beakers with lip, assorted sizes.
1 dozen 2-inch watch-glasses.
1 6-inch water-bath, copper, with rings.
1 glass alcohol lamp, 4 ounces.
1 Berzelius alcohol-lamp with stand and rings.
1 fine balance, 100 grammes capacity.
1 set of fine weights, 100 grammes down.
4 each volumetric flasks, marked 100, 250, 500 c.c.
6 litre flasks, glass-stoppered, 1000 c.c.
3 mixing cylinders, glass-stoppered, 1000 c.c.
1 nest Berzelius' beakers, 1 to 4.
12 sheets each blue, red and yellow test-paper.

CHEMICALS.

Acetic acid.
Acetic acid, glacial.
Alcohol (absolute).
Alcohol (common).
Ammonic carbonate.
Ammonic chloride.
Ammonic hydrate.
Ammonic molybdate.
Ammonic nitrate.
Ammonic oxalate.
Ammonic sulphocyanide.
Ammonic sulphhydrate.
Argentic nitrate.
Baric carbonate.
Baric chloride.
Bromine water.
Calcic chloride.
Chlorine water.
Citric acid.
5 grammes coralline } indicators.
5 " methyl-orange } indicators.
5 " phenolphthalein } indicators.
Distilled water.
Ferric chloride.
Ferrous sulphate (crystals).
Fine white pure sand.
Hydrochloric acid (concent.).
Hydro-disodic phosphate.
Indigo solution.
Iron wire and plate.
Magnesic chloride crystal.
Magnesic sulphate.
Nitric acid (concent.).
Nitro - hydrochloric acid (aqua regia).
Oxalic acid (crystals).
Platinic chloride.
Potassic carbonate (dry)
Potassic chlorate.
Potassic dichromate.
Potassic ferricyanide.
Potassic ferrocyanide.
Potassic hydrate.
Potassic permanganate (crystals).
Potassic and sodic carbonates (mixed).
Potassic sulphocyanide.
Sodic acetate.
Sodic carbonate.
Sodic chloride.
Sodic nitrate (crystals).
Sulphuric acid (concent.).
Sulphuretted hydrogen.
Uranic acetate.
Zinc, granular.

CHAPTER IX.

LIST OF FLORIDA PHOSPHATE MINING COMPANIES.

(*Those marked with an asterisk are actually working.*)

Name.	*Address.*	*Capital.*
*Arcadia Phosphate Co	De Soto County; office, Savannah, Ga.	.....
*Albion Phosphate Mining and Chemical Co.	Baltimore, Md.	$500,000
Albion Mining and Mfg. Co.	Gainesville	300,000
Albion Phosphate Co.	Gainesville	300,000
Alachua Phosphate Co.	Gainesville	300,000
Alafia River Phosphate Association.	Bartow	100,000
*Alafia River Phosphate Co.	Bartow	1,000,000
Alafia Phosphate Co.	Jacksonville	35,000
American Mining and Imp't Co.	Bartow	1,200,000
*Anglo-American Phosphate Co.	Ocala	400,000
*Anglo-Florida Phosphate Co	....	.....
*Archer Phosphate Co.	Gainesville	100,000
Atlantic and Gulf Phosphate Co.	Bartow, Fla.; and Charleston, S. C.	10,000
Boca Grande Phosphate Co.	De Soto County; deposit worked on Caloosahatchie River	250,000
*Black River Phosphate Co.	Clay County	200,000
Berkley Phosphate Co.	Bartow.	40,000
*Bowling Green Phosphate Co.	.....	.....
*Bradley's Phosphate Mines.	.....	.....
*Belleview Phosphate Co.	Jacksonville	600,000
*Charlotte Harbor Phosphate Co.	Fort Ogden, De Soto County.	.....
Cove Bend Land Phosphate Co.	Inverness, Citrus County.	200,000
Columbian Phosphate Co.	Jacksonville	.....
Chicago Phosphate Co.	.....	.....
*Compagnie des Phosphates de France	Ocala	1,000,000
*De Soto Phosphate Co.	Zolfo, De Soto County; office, Atlanta, Ga.	250,000
*Dunnellon Phosphate Co.	Dunnellon, Marion County	1,250,000
*Deacon Phosphate Co.	.....	.....
E. C. Evans' Mining Co.	Dunnellon, Marion County	.....
*Early Bird Phosphate Co.	Marion County	100,000
Empire State Phosphate Co.	Citrus County	125,000

Name.	*Address.*	*Capital.*
*Excelsior Phosphate Co	.....	.....
*Fort Meade Phosphate, Fertilizer, Land and Improvement Co	Fort Meade, Polk County	50,000
Florida Phosphate Co., Limited	Phosphoria, Polk County	1,000,000
Farmers' Co-operative Mfg. Co., Georgia	.....	200,000
Florida Blue Rock Phosphate Co.	Bowling Green	150,000
*Florida Phosphate and Fertilizer Co	Tallahassee	100,000
Florida Phosphate Co	Ocala	210,000
Glenn Alice Phosphate Co	Bay Hill, Sumpter County	.....
*Gulf Phosphate Mining and Manufacturing Co	Liverpool, De Soto County	240,000
Gainesville Phosphate Co	Gainesville	50,000
Globe Phosphate Mining and Mfg. Co	Ocala	2,000,000
Great Southern Phosphate Co	.....	30,000
*Homeland Pebble Phosphate Co.	Homeland, Polk County	100,000
Homeland Mining and Land Co	Homeland, Polk County	120,000
*High Springs Phosphate Comp'y	High Springs	.....
*Hartshorn Phosphate Co	.....	.....
*Hamburg Phosphate Co	Inverness, Citrus County	.....
*Illinois Phosphate Mining Co	Marion County	225,000
*Ichetucknee Phosphate Co	Jacksonville	30,000
Jackson and Peace River Phosphate Co	Apopka, De Soto County	1,000,000
Jacksonville and Santa Fé Phosphate Co	.....	500,000
Lee County Phosphate Co	Fort Myers, Lee County; deposit on Caloosahatchie River	250,000
Lay Phosphate Co	Bartow	575,000
La Fayette Land and Phosphate Co	Appalachicola	10,000
Lake City Land and Timber Co	.....	50,000
Lake City Phosphate Co	Lake City	100,000
*Little Bros.' Fertilizer Co	South Jacksonville	100,000
*Land Pebble Phosphate Co	Bartow	.....
*Lake Hancock Pebble Phosphate Co	.....	.....
*Moore & Tatum Phosphate Co	Bartow, Polk County	100,000
Madison Phosphate Co	Madison	50,000
Magnolia Phosphate Co	Gainesville	50,000
*Marion Phosphate Co	Savannah	5,000,000
Marion and Citrus Phosphate Co.	Ocala	200,000
*Mastodon Pebble Phosphate Co.	.....	.....
*Netherlands Phosphate Company	Ocala	.....

Name.	*Address.*	*Capital.*
*North and South Alafia River Phosphate Co		360,000
*Ocala and Blue River Phosphate Co	Ocala	780,000
*Orange County Phosphate Co	Orlando	10,000
*Peace River Phosphate Co	De Soto County, Arcadia, Fla.; principal office, New York	300,000
*Peruvian Phosphate Co		
Pharr Phosphate Co	Bartow, Polk County	
Prospect Phosphate Co	Dunnellon, Marion County	
Panasofkee Phosphate Co	Ocala	100,000
Paola Creek Phosphate Co.,	Bartow	150,000
*Pebble Phosphate Co. of Jacksonville	Jacksonville	
*Perrill Phosphate Co		
*Pitts Phosphate Co		
*Plate Rock Phosphate Co	Alachua County	
South Florida Phosphate Co	Liverpool, De Soto County	240,000
Standard Phosphate Co	Orlando	500,000
*Standard Phosphate Co	Ocala	2,000,000
*Stonewall Phosphate Co	Jacksonville	500,000
*Standard Pebble Phosphate Co		
*Stranathann Phosphate Co	Marion County	
*Tampa Phosphate Co	Tampa, Hillsboro County	25,000
*Terraceia Phosphate Co	Works in Manatee and Polk Counties	1,000,000
*Thann Phosphate Co		
Trenton Phosphate Co		
*Virginia-Florida Phosphate Co	Fort Meade, Polk County	120,000
Withlacoochee River Phosphate Co	Panasofkee, Marion County	400,000
Waukulla Lumber and Phosphate Co	Tallahassee	10,000
Waukulla Phosphate Co	Crawfordsville	10,000
Wekiva Phosphate Co	Sanford	10,000
Whittaker Phosphate and Fertilizer Co.	Homeland, Polk County	500,000
Zeigler Phosphate Co	Ocala	25,000

THE END.

INDEX.

ACID CHAMBERS.
Arrangement of drips, windows and caps in..... 92
Construction of..... 90
Dimensions of..... 90
Exit gases from..... 94
General hints in management of..93, 94
Pressure of steam in..... 90
Reactions of gases in..... 93
Regulation of nitre supply in..... 93
Sprengel pump in..... 90
Thickness of lead for, and amount of space in..... 90
ACID PHOSPHATE OF LIME.
Composition of..... 107
Production of, in the manufacture of superphosphate..... 111
ACID siphon or "egg," Description of..... 98, 99
ACID solution, Concentration of..... 130
ACIDS and alkalies, Table for systematic analysis of..... 173
AGRICULTURAL products, Value of, in U. S..... 14
AGRICULTURE, Theory of scientific.... 9
AIR SUPPLY.
Importance of regulating, in sulphuric acid manufacture..... 89
Regulation of, in pyrite burners..... 88
" " for burning brimstone..... 88
ALKALIES and acids, Table for systematic analysis of..... 173
ALUMINA AND IRON.
Combination of, in Florida phosphates 154, 155
Determination of oxides of..... 150–153
Elimination of, from Florida phosphates..... 74
Estimation of, in raw phosphates.150, 151
Glaser's method of estimating...152, 153
In Florida phosphates..... 74, 81
AMMONIA.
Citrate solution of..... 170
Hydrate solution (normal) of..... 168
Nitrate solution of.....170
Oxalate solution of..... 170
Table showing strength of various solutions of..... 175
ANALYSIS.
Determinations necessary in..... 144
Divergence in, of phosphates.26, 139, 140
Of alkalies and acids, Table for. 173
" brimstone..... 162
" chalk or limestone..... 163
" fertilizers, Normal solutions useful in.....167–171
ANALYSIS.
Of Florida phosphates..... 80
" phosphates, Volumetric.....157–158
" pyrites ores 159–161
" raw phosphates 138, 144, 154
" soils..... 13
" sulphuric acid 163
" superphosphates.....155–157
Preparation of sample for phosphate..... 144
Selected methods of..... 138
Volumetric, of phosphates.....157, 158
APATITES.
Average cost delivered at Montreal 42
" " of mining.. .....40, 41
Canadian, see CANADIAN APATITES.
Chemical composition of..... 35
Combination of various bodies determined in phosphate..... 154
Continuity of veins of..... 39
Coste, Eugene, on the origin of Canadian..... 36
Dawson, Sir William, on Canadian. 35
Geological aspect of Canadian..... 27
In rocks of Laurentian period..... 27
Methods of mining, in Canada..34, 40, 42
Mines, Principal working of, in Canada..... 28
Output of, from 1877 to 1890 43
Probable origin of Canadian 35, 37, 38, 39
Ratio of, to other rocks in Canadian mines..... 40
Selling price of, in 1890..... 43
Selwyn, A. R. C., on the origin of Canadian..... 36
Transportation of..... 42
Values, Yearly, of..... 43
APPARATUS, List of chemical and other, chiefly required in "phosphate mining" and "fertilizer factory" laboratories... 177
ARCHÆAN rocks, Composition of..... 27
ARTESIAN wells in Florida..... 67
ARTIFICIAL heat, Evil effects of, when used to dry superphosphates..... 113
ASSIMILABILITY of phosphates.....18–22
ATOMIC weights, Table of 164
BARIUM CHLORIDE.
Standard solution of..... 169
Table showing strength of various solutions of..... 175
BARTOW as a phosphate-producing region..... 76
BAUMÉ degrees compared with specific gravity..... 173
BOOM in Florida phosphates..... ... 63

BOUSSINGAULT on the migration of phosphates in plants..... 17
BRIMSTONE.
Air supply in burning..... 88
Analysis of..... 162
Cost of manufacturing H_2SO_4 from. 104
In sulphuric acid manufacture..... 86
Moisture, Determination of, in.... 162
Possible yield of H_2SO_4 from..... ... 102
Sulphur, Determination of, in..... 162
CALCINING and drying Florida phosphates..... 75
CALCINING phosphates, Fallacy of, exposed..... 116
CANADIAN APATITES.
Chemical composition of..... 35
Companies now engaged in mining. 28
Cost of production of..... 42
Dawson, Sir William, on..... 35
Geological aspects of..... 27
Methods of mining.....29, 34, 40. 42
Natural impediments in the way of mining in Canada..... 42
Necessity of a change in the methods of mining in Canada..... 44
Occurrence of.....27, 35
Origin of.....35-40
Output of, mines from 1877 to 1890.. 43
Principal working mines of..... 28
Value of lands containing..... 29
Veins of..... 39
Wasteful methods of mining..... 42
CANADIAN PHOSPHATES.....29-42
Equipment necessary for mining of. 34
Mining, Extravagant method of.... 42
CARBONATE of lime as an important ingredient in the manufacture of superphosphates 112
Estimation of, in phosphates..... 145
CARBONIC ACID GAS.
Estimation of, in phosphates..... 145
Schrötter's apparatus for estimation of..... 146
CENOZOIC time..... 45
CHALK OR LIMESTONE.
Analysis of..... 163
Determination of magnesia in..... 163
CHAMBER ACID.
For decomposition of phosphates, Table of quantity of 110
In manufacture of phosphoric acid, Table of..... 128
SO_3 and H_2SO_4 in, Table showing value of..... 108
CHEMICAL knowledge required in the manufacture of fertilizers..... 111
CHEMICALS, General list of those, chiefly required in phosphate analyses..... 178
CINDERS from pyrites burning, Value of..... 87
CITRATE.
Insoluble P_2O_5, Determination of, in superphosphates..... 156
Soluble P_2O_5, Determination of, in superphosphates..... 157
Soluble phosphates 111, 112
CLAYEY soils..... 11
COMBINATION OF
Iron and alumina in Florida phosphates.....154, 155
Raw materials used in the manufacture of superphosphate..... 125
Various bodies determined in phosphate analysis..... 154
COMBINED water and organic matter in raw phosphates, Determination of..... 144
COMPANIES, Bogus, in Florida and their evil influence..... 82
COMPANIES NOW ENGAGED IN
Canadian apatite mining..... 28
Florida phosphate mining... 179, 180, 181
South Carolina phosphate mining, 55, 56
COMPOSITION OF
Phosphoric acid solution of 45° B... 131
Plants..... 13
Principal phosphates 20
Superphosphates as manufactured in United States 126
CONCENTRATION of acid solutions.... 130
CONDENSING plant for the fertilizer factory.....134-137
CONSTRUCTION of fertilizer works.123, 124
CONTRACTS, Proposed modifications in present forms of making.....141, 142
CONVERSION of thermometric degrees 165
COOSAW Mining Co., History and earnings of.....56-58
COPPER.
Determination of, in pyrites..... 159
Estimation of, as subsulphocyanide in pyrites ores and residues..... 161
CORALLINE, as an indicator..... 167
CORENWINDER, on the migration of phosphates in plants..... 17
COST OF PRODUCTION OF
Canadian apatites..... 42
Florida phosphates.....75, 77, 79
High-grade superphosphates..... 133
Phosphoric acid..... 133
South Carolina phosphates.....59, 60
Sulphuric acid.....104, 105
COSTE, Eugene, on the origin of Canadian apatites..... 36
CROPS, Percentage of mineral matter in the U. S.....14-16
CRUST of the earth, Geological divisions of the..... 27
DAWSON, Sir W., on probable origin of Canadian apatite..... 35

DECOMPOSITION of phosphates, Table of quantity of chamber acid required for 110
DECOMPOSITION of rocks 10
DEFECTS in the raw material used in superphosphate manufacture and how to remedy them 113
DEGREES Baumé compared with specific gravity 173
DEPOSITS.
Of nodular and amorphous phosphates 45
Of phosphate in America 25
DEVELOPMENT of Florida phosphate deposits 63
DIFFICULTIES in the manufacture of superphosphate 112
DIRECTIONS for manufacturing superphosphate 123-126
DISCOVERY OF
Charleston phosphates, Professor Holmes on 45
Mineral deposits of phosphates 19
Phosphate in Florida 63
The fertilizing value of phosphates. 19
DISINTEGRATION OF PHOSPHATES.
In the factory 117-123
In the soil 22
Liebig's theory of 22
DIVERGENCE in analysis of phosphates 26
DREDGES, Mining by means of floating 74
DREDGING system in South Carolina 51, 52
DRIFT deposits in South Carolina ... 73, 75
DRIPS, Arrangement of, in manufacture of H_2SO_4 92
DRYING.
And calcining Florida phosphates ... 75
Phosphates in South Carolina 53, 54
Washing and, of phosphates 75
EARTH'S crust, Geological divisions of the 27
EOCENE era 45
FARMER, Relative value of phosphate to the 23
FERTILIZER ANALYSIS, Normal solutions useful in 167-171
FERTILIZER INDUSTRY.
Molecular weights of substances used in 171, 172
Per cent. composition of substances used in 171, 172
Symbols of substances used in the, 171, 172
FERTILIZER WORKS.
Amount of fluorine in gases from . 134
Fume condenser for, Sketch of .. 135-137
General outline and plan of 123, 124
Nature of the fumes from 134
FERTILIZER WORKS.
Noxious fumes from 134
FERTILIZERS.
Chemical knowledge required in the manufacture of 111
Manufacturers of, in South Carolina, List of 60
Production of, in South Carolina 60, 61
FERTILIZING value of phosphates, Discovery of 19
FLORIDA.
Artesian wells in 67
Mining law in 77, 78
Topographical aspect of 64, 65, 66, 67
FLORIDA PHOSPHATE.
Analysis, Typical, of 80
Boom in 63
Calcining, Fallacy of 116
Chemical composition of a sample of 108
Companies now engaged in mining ... 179
Composition, Typical, of 80
Cost of production of 75, 77, 79
Deceptive indications of deposits of. 72, 73
Deposits, Development of 63
Discovery of deposits of 63
Drying and calcining, Methods of 75
Exploration, Systematic, of deposits of 51
Formation of, Theories on the. 68, 69, 70, 71, 72
Geological aspect of, deposits 67, 68
Iron and alumina, Elimination of, from 74
Iron and alumina in 80
Lands and their inflated values 63, 82
Maps of, deposits 78
Mining, by floating dredges 78, 79
Pebble mining, Methods of 77, 78
Physical aspect of, General 80
Pockety nature of deposits of 72
Rock mining, Methods of 74, 75, 76
Speculative dealings in, lands 63
Suggestions for working, deposits 76
Washed and dried 75
FLORIDA PHOSPHATE MINES.
Companies now working, Partial list of 179
Extent and aspect of 64
In Lakeland and neighborhood 66
In Peace River and its tributaries 77
In pebble regions 78
Jeffrey Manufacturing Co.'s plant for working 75
Negro labor in 83
Suggestions for working 74, 75
Thickness of phosphate stratum in. 72, 76
FLUORINE.
Amount of, in gases from fertilizer works 134-137
Estimation of, in raw phosphates 149

FORMATION.
Of the globe..... 10
" soils..... 11
FRISBEE-LUCOP phosphate mill....120-123
FUME condenser for fertilizer works, Sketch of 135-137
FUMES from fertilizer works.....134-137
FURNACE, Varieties of, in pyrites burning..... 86
GAY-LUSSAC towers, Construction and use of..... ...94, 95
GEOLOGICAL.
Canadian apatite deposits, aspects of..... 27
Classification of tertiary rocks...45, 46
Division of the earth's crust..... 27
Florida phosphate deposits, aspects of.....67, 68
Maps of Florida phosphate deposits 78
South Carolina phosphate deposits, aspects of..... 48
GLASER'S method of estimating iron and alumina in raw phosphates, 152, 153
GLOBE, Formation of the..... 10
GLOVER TOWERS, Construction and use of.....95-101
Packing of..... 97
GRAIN crop, Percentage of phosphoric acid in..... 15
GRIFFIN phosphate mill.....118-120
GRINDING phosphates, Various methods of.....117-123
HAY Crop.
Percentage of mineral matter in the. 16
Phosphoric acid in the..... 16
HIGH-GRADE SUPERPHOSPHATES.
Arguments in favor of..... 127
Chemical theory and desirability of manufacture of..... 126
Cost of manufacturing..... 133
Manufacture of..... 132
Plant used in manufacture of..... 132
Practical examples in the manufacture of..... 129
Tables for the manufacture of...128, 131 132
HOLMES, Professor, on the discovery of Charleston phosphates..... 48
HYDROCHLORIC acid table..... 176
INDICATIONS of Florida phosphate deposits, Deceptive 72
IRON.
Estimation of, in limestone..... 163
" " " phosphates..... 151
" " " pyrites..... 161
Titration by permanganate of..... 171
IRON AND ALUMINA.
Combination of, in Florida phosphates..... 154, 155
IRON AND ALUMINA.
Elimination of, from Florida phosphates..... 74
Estimated by Glaser's method.. 152, 153
Estimation of,in raw phosphates, 150, 151
In Florida phosphates..... 80
In phosphates 21, 139
In superphosphates..... 112
Oxides of, Determination of.... 150-153
JEFFREY Manufacturing Company's plant for mining, washing and drying Florida phosphates (illustrated)..... 75
LAKELAND, Florida, Phosphate mines in..... 66
LAURENTIAN period..... 27
LIEBIG'S theory of disintegrating phosphates 22
LIME.
Estimation of, in limestone..... 163
Estimation of, in raw phosphates... 153
Insoluble siliceous matter in, Determination of..... 163
Iron in chalk or, Determination of. 163
Magnesia in, Determination of 163
Mineral phosphate of, Action of sulphuric acid on..... ... 108
LIMESTONE, Analysis of..... 163
LIMY soils..... 12
LOW-GRADE phosphates, Utilization of..... 128
MAGNESIA.
In limestone or chalk, Determination of..... 163
In raw phosphates, Determination of..... 154
Mixture, Preparation of..... 170
MANUFACTURE OF
High-grade superphosphates.....132-134
Phosphoric acid.....129-133
Sulphuric acid.....84-102
Superphosphates.....106-128
MAP OF
Florida phosphate deposits..... 78
South Carolina phosphate deposits. 48
MEASURES and weights of the metrical system..... 165
METHYL-ORANGE as an indicator..... 167
METRICAL system, Measures and weights of the..... 165
MILL.
Frisbee-Lucop..... 121
Griffin phosphate..... 118-120
Sturtevant, phosphate..... 117, 118
MINERAL.
Deposits of phosphates, Discovery of. 19
Matters in the crops of the United States.....14-16
Phosphates of lime, Action of sulphuric acid on..... 108

MINING LAW.
In South Carolina....56-57
In Florida....77, 78
MIOCENE era.... 45
MIXERS used in production of superphosphates.... 124
MOISTURE in raw phosphates, Determination of 144
MOLECULAR weights of substances used in the fertilizer industry...171, 172
NEGRO labor in Florida.... 83
NEUTRAL phosphate of lime, Chemical composition of.... 107
NITRE in sulphuric acid manufacture.... ....85, 92
NITRIC ACID.
In sulphuric acid manufacture. 85
Table.... 176
NODULAR deposits of phosphate of lime.... 45
NORTH STAR mine, Canada, Description of the.... 30
ORGANIC matter, Estimation of combined water and, in phosphate analysis.... 144
ORIGIN of phosphates.. ... 17, 68, 69, 70, 71
OUTPUT OF
Canadian apatite mines, 1877 to 1890. 43
Superphosphates in South Carolina....60, 61
OXIDES OF IRON AND ALUMINA.
Determination of, in South Carolina phosphates.... 150-153
Estimated by Glazer's method..152, 153
OXYGEN in sulphuric acid manufacture.... 85
PACKING.
Of Gay-Lussac Tower.... 95
Of Glover tower.... 97
PEACE RIVER, Florida, Phosphate mines in.... 73
PHENOLPHTHALEIN as an indicator... 167
PHOSPHATES.
Action of sulphuric acid on insoluble varieties of....107, 108
Alumina and iron, of....21, 139
Amorphous and nodular, Deposits of 45
Analysis of, Chemicals required in. 178
Analysis of, Determinations to be made in 144
Analysis of, Divergence in...26, 139, 140
Analysis of, Methods of.....138, 144, 154
Analysis, Volumetric, of. 157, 158
Analytical list of best known..... 20
Analyzing, Selected methods of..... 138, 144-154
Assimilability of.... 18-22
Buying and selling, Contracts for... 141, 142
Canadian.... ....29, 42
PHOSPHATES.
Chamber acid required to decompose, Table showing quantity of.. 110
Chemical composition of a sample of Florida.... 108
Citrate soluble.... ....111, 112
Combination of various bodies determined in.... 154
Commercial value of.....25, 138, 149
Composition of the principal..... 20
Consumption of, World's approximate.... 138
Contracts for buying and selling.... 141, 142
Cost of production of Florida...75, 77, 79
Cost of production of South Carolina.... 59-60
Decomposition of, Table showing quantity of chamber acid of any strength for.... 110
Deposits of, in America.... 25
Discovery of fertilizing value of.... 19
Discovery of mineral deposits of.... 19
Disintegration of, in the factory..117-123
Disintegration of, in the soil.... 22
Disintegration of, Liebig's theory of 22
Drying of, Methods of, in South Carolina.... . 53, 54
Farmer, Relative value of, to the.... 23
Florida, see FLORIDA PHOSPHATE.
Fluorine in raw, Determination of.. 149
Grinding, Methods of....117-123
Iron and alumina, Determination of, in.... ....150, 151, 152, 153
Iron and alumina in Florida....154, 155
" " " " 21, 139
Iron in, Estimation of.... 151
Liebig's theory on raw.... .. 22
Lime in raw, Estimation of.... 153
Location of deposits of.... ... 73
Low-grade, Utilization of.... 128
Magnesia in raw, Determination of, 154
Mill, Frisbee-Lucop's.... 121
Mill, Griffin's.... ....118, 120
Mill, Sturtevant's.... ..117, 118
Moisture in raw, Determination of. 144
Nodular and amorphous, Deposits of. 45
Of lime, mineral, Action of sulphuric acid on.... 108
Of lime, neutral, Chemical composition of.... 107
Organic matter, Determination of combined water and, in raw.... 144
Origin of.... 17
Phosphoric anhydride in raw, Determination of 148
Plants, Migration of, in.... 17
Raw, used in various soils.....23, 24
Sampling, at the mines.....142, 143
" before shipment.....143, 144
Selling and buying, Contracts for.141, 142

PHOSPHATES.
Siliceous, insoluble, matter, Determination of, in raw..... 147
Soil, Necessity for, on the..... 17
Soil, Reversion of, in the..... 23
Soluble and precipitated..... 24
South Carolina, see SOUTH CAROLINA.
Sulphuric anhydride in raw, Determination of..... 147
Tertiary strata, Workable strata of. 46
Value of, to the farmer, Relative .. 23
Volumetric analysis of..... ...157, 158
Water, combined, and organic matter, Determination of, in raw..... 144
World's approximate consumption of..... 138

PHOSPHORIC ACID.
Calculations connected with the manufacture of..... 132
Chamber acid required in manufacture of, Table of..... 128
Chemical composition of. 107
Commercial value of, Fixing....138, 139
Concentration of weak solutions of. 130
Cost of manufacturing..... 138
Determination, Volumetric, of..157-159
Gases produced in manufacture of, Volume of..... 88
Grain crop, Percentage of, in..... 15
Hay crop, Percentage of, in..... 16
High-grade superphosphates, Table of quantities of phosphoric acid required in the manufacture of..... 131
Manufacture of, on the large scale from low-grade ores 129-133
Plant required in manufacture of, 129, 130
Solution of 45° B., Composition of.. 131
Solutions of, Concentration of weak 130
Solutions of, Strengths of 174
Straw, Percentage of, in..... 15
Superphosphate manufacture, set free in the..... 111
Superphosphate manufacture, Table of quantities of phosphoric acid required in 131
Table for use in manufacture of high-grade superphosphates..... 131
Table showing strength of various solutions of..... 174
Tribasic, Composition of..... 107
Volumetric determination of....157-159

PHOSPHORIC ANHYDRIDE..... 106
Chemical composition of..... 106
Determination of, in raw phosphates..... 148
Determination of, in superphosphates.....155-157
Determination of, volumetrically.. 157, 158

PHOSPHORIC ANHYDRIDE.
Determination of water-soluble, in superphosphates. 155
PLANT growth, Elements of..... 12
PLANT REQUIRED IN MANUFACTURE OF
Phosphoric acid.....129, 130
Sulphuric acid..... 90, 91
Superphosphate.....123, 124
PLANTS.
Composition of..... 13
Life of..... 13
Migration of phosphates in..... 17
PLIOCENE era..... 45
PRESSURE of steam in sulphuric acid chambers..... 90
PYRITE burners, Regulation of air supply in..... 88
PYRITES.
Air supply in burning..... 88
Analysis of.....159, 161
Average composition of..... 103
Burning, Furnace used in..... 86
Cinders from burning, Value of..... 87
Copper, Determination of.... ...159, 161
Insoluble siliceous matter, Determination of..... 160
Iron in, Determination of..... 161
Methods of sampling. 159
Residues, Utilization of..... 87
Samplings of, for analysis..... 159
Sulphur in, Determination of..... 160
Sulphuric acid manufacture, Use of, in..... 86
PYROXENE, Occurrence and characteristics of..... 29
QUEBEC, Canada, Apatite deposits of. 27
REACTIONS in sulphuric acid manufacture..... 85
ROCKS.
Archæan..... 27
Decomposition of..... 10
Limestone, in Florida..... 67
Of the Laurentian period..... 27
Phosphates, of S. Carolina..... 46
Tertiary, Classification of... .....45, 46
Varieties of..... 10
SAMPLING.
Phosphate at the mines..... 143
Phosphate before shipment..... 144
Pyrites for analysis..... 159
SANDY soils..... 11
SCHEURER-KESTNER'S experiments with the Glover tower.....100, 101
SCHRÖTTER'S CO_2 apparatus..... 146
SELLING prices of South Carolina phosphate..... 60
SELWYN, A. R. C., on the origin of Canadian apatites..... 36
SILICEOUS MATTER, INSOLUBLE.
In limestone, Determination of.... 163
In pyrites, Determination of..... 160

SILICEOUS MATTER, INSOLUBLE.
In raw phosphates, Determination of 147
SOIL.
Disintegration of phosphates in the. 22
Formation of the..... 11
Limy..... 12
Raw phosphates, Use of, in various, 23, 24
Varieties of..... 11
SOUTH CAROLINA.
As a pioneer in the fertilizer industry..... 60
Drying of phosphates, Methods of. 53, 54
Fertilizers, Production of, in..... 61
Manufacture of fertilizers in..... 60
Manufacturers of fertilizers in, List of..... 60
Mining law in..... ...56, 57
SOUTH CAROLINA PHOSPHATE.
Companies now engaged in mining. 55, 56
Continuity of, deposits... 48
Cost of production of.....59, 60
Deposits... 46-62
" Unexploited, of..... 61
Dredging scoops used in mining...51, 52
Excavating and exporting, Methods of.....53, 54
Exploring, Methods of, deposits ... 49
Extent of deposits near Charleston. 48
Geological formation of, deposits... 48
Holmes, Professor, on the discovery of, deposits..... 46
Map of, deposits..... 48
Mining of, Methods of 53-55
Nature of material overlying.....49, 50
Oxides of iron and alumina in, Determination of.....150-153
Pit sinking in..... 49
Production of, Annual..... 54
River and land..... 51
Rocks..... 46
Specific gravity of 52
Table of annual production of..... 54
Thickness of strata in, deposits..... 49
Typical sections of, deposits.....50, 51
Unexploited areas of..... 61
SOUTH CAROLINA SUPERPHOSPHATES, Output of.....60, 61
SPECIFIC GRAVITY.
Comparison of degrees Baumé with 173
How to determine..... 166
Of South Carolina phosphates..... 52
SPECULATIVE dealing in Florida phosphate land.....63, 82
SPRENGEL pump in acid chambers.... 90
STANDARD solutions.....167-170
STEAM pressure in sulphuric acid chambers..... 90
STOICHIOMETRY 165
STRAW.
Percentage of mineral matter in.... 14
Percentage of phosphoric acid in ... 15
STURTEVANT'S phosphate mill.....117, 118
SUBSULPHOCYANIDE, Estimation of copper as, in pyrites ores and residues..... 161
SULPHUR.
Estimation of, in brimstone.... 162
" " in pyrites..... 160
SULPHURIC ACID.
Action of, on mineral phosphate of lime..... 108
Air supply in manufacture of.....88, 89
Analysis of... 163
Chambers 90-93
Chemistry of manufacturing process of.....84-90
Composition of pure..... 102
Cost of manufacture of, from pyrites and brimstone..... .. 104, 105
Gay Lussac and Glover towers in the manufacture of.....91-101
Manufacture of.....84-102
" " Early methods of.. 84
Manufacture of, Plant required in. 90, 91
Nitre in manufacture of..... 85
Nitre supply in, Regulation of..... 92
Oxygen in manufacture of..... 85
Plant required in manufacture of. 90, 91
Pumping siphon, or "egg".....98, 99
Pyrites in manufacture of..... 86
Reactions in manufacture of..... 85
Table for preparing various strengths of, by adding water..... 174
Table showing value of chamber acid in SO_3 and H_2SO_4 according to Baumé..... 108
Yields of, in actual practice from pyrites and brimstone..... 102
SULPHURIC ANHYDRIDE.
Determination of, in raw phosphates 147
Table showing value of chamber acid in..... 108
SUPERPHOSPHATE MANUFACTURE.
Chemical equations involved in ... 109
Chemistry of 106
SUPERPHOSPHATES.
Acid phosphate of lime, Production of, in the manufacture of..... 111
Analysis of.... 155-158
Chemical theory of high-grade, manufacture 126
Citrate soluble, Water and..... 112
Composition of, as manufactured in United States..... 126
Composition of, Variability in..... 106
Consumption, World's, of..... 138
Cost of producing high-grade 132
Cost of transportation of..... 127

SUPERPHOSPHATES.
Desirability of high-grade, manufacture..... 126
Determination of citrate insoluble P_2O_5 in..... 156
Determination of citrate soluble P_2O_5 in 157
Determination of total P_2O_5 in.... 157
Determination of water soluble P_2O_5 in..... .....155, 156
Difficulties in the manufacture of.. 112
Drying, Methods of..... 113
Equations involved in manufacturing..... 109
Examples of scientific and accurate methods of manufacturing... 114, 115
High-grade, Arguments in favor of. 127
" " Cost of Manufacturing. 133
" " Manufacture of....126, 132
" " Plant used in manufacture of..... 132
" " Practical examples in the manufacture of. 129
" " Tables for the manufacture of 128, 131, 132
Iron and alumina in..... 112
Manufacture of..... 106-128
" " Calculations employed in.....110, 111
" " Difficulties in..... 112
" " Directions for...123-126
" " Equations involved in..... 109
" " Examples of scientific.....114, 115
" " high-grade.....132-134
" " Plant required in, 123, 124
Merchantable, Methods of making, dry and..... 113
Mixers used in the production of... 124
Mixture of the raw materials in the manufacture of..... 123-125
Moisture in, Determination of..... 155
Output of, in South Carolina.....60, 61
Phosphates, mono-calcic, and di-calcic, Production of, in the manufacture of..... .. 111
Phosphoric acid set free in the manfacture of.... 111
Phosphoric anhydride in, Determination of..... 155-157
Plant required in manufacture of, 123, 124
Raw Material, Combination of, used in the manufacture of..... 125
Raw Material, Defects in the, used in the manufacture of, and how to remedy them..... 113
Raw Material, Mixture of, used in the manufacture of.....123-125
SUPERPHOSPHATES.
Raw Material, Qualities of, in manufacturing..... 111
Sampling, Method of..... 155
Table showing the quantity of chamber acid of any strength required to decompose any phosphate of known composition. . . 110
Water and citrate soluble..... . 112
SYMBOLS of substances used in the fertilizer industry.....171, 172
TABLES.
For preparing sulphuric acid of various strengths by adding water 174
For systematic analysis of alkalies and acids..... 173
Of atomic weights..... 164
Showing amount of chamber acid of various strengths required in the manufacture of phosphoric acid from natural phosphates in relation to the production of high-grade "supers"..... 128
Showing annual production of Canadian apatite..... 43
Showing annual production of South Carolina phosphate..... 54
Showing quantities of phosphoric acid required in the manufacture of high-grade superphosphates from mineral phosphates..... 131
Showing quantity of chamber acid of various strengths required to decompose any phosphates of known composition..... 110
Showing strengths of various solutions of ammonia 175
Showing strengths of various solutions of barium chloride.. 175
Showing strengths of various solutions of hydrochloric acid. 176
Showing strengths of various solutions of nitric acid 176
Showing strengths of various solutions of phosphoric acid..... 174
Showing the value of chamber acid in SO_3 and H_2SO_4, according to Baumé..... 108
TERTIARY.
Age, Characteristics of..... 45
" Subdivision of..... 45
Rocks, Geological classificaion of. 45, 46
Strata, Workable phosphate deposits of..... 46
THERMOMETRIC degrees, Conversion of 165
TILLMAN, Governor, on the Coosaw Mining Co 56-58
TOPOGRAPHICAL aspect of Florida... 64-67
TRIBASIC phosphoric acid, Chemical composition of..... 107

URANIUM acetate solution 169
VALUES of agricultural products 14
VOLUMETRIC estimation of phosphoric acid.....157-159
WATER, combined, and organic matter in raw phosphates, Determination of..... 144
WASHING and drying Florida phosphates 75
WEIGHTS.
Measures and, Metrical system of.. 165
Table of atomic..... 164
WELLS, Artesian, in Florida..... 67
WINDOWS in sulphuric acid chambers 92

BOOKS

ON

Metallurgy,

Electricity, **Mining,**

Assaying, **Chemistry,**

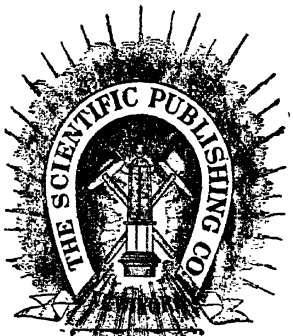
Geology, **Mineralogy,**

Railroading, **Mechanics,**

Surveying, **Hydraulics,**

Architecture, **Roads and Bridges,**

Mathematics, **Sanitary Engineering,**



and Other Subjects.

Magazines and Papers Furnished.

☞ **SPECIAL DISCOUNTS GIVEN**

to Libraries, Educational Institutions, and on Important Cash Orders. ☜

Those desiring to investigate any scientific or technical subject can learn which are the best books and sources of information on the same by writing to

The Scientific Publishing Company,

Publishers and Booksellers,

NEW YORK:
27 Park Place.

LONDON:
20 Bucklersbury.

Parliamentary Tactics

FOR THE USE OF THE

PRESIDING OFFICER

AND

PUBLIC SPEAKERS.

BY

HARRY W. HOOT.

This little manual on Parliamentary Tactics is arranged in a way especially adapted for use by "the Chair" from such standard authorities as Roberts, Cushing, Matthias, Jefferson, and Crocker.

Where the authorities differ, the view most conformable to the latest and most thoroughly established usages of Parliamentary Law has been accepted.

The table of motions has been arranged by placing on the margin the names of such motions as are used in Common Parliamentary Practice, with their classification and order of procedure in a deliberative body, being placed at the top of the book, and descending in regular consecutive order will be found those having the next highest order of precedence, viz.: Privileged questions, Incidental questions, Subsidiary motions, and Main questions. Thus can be seen without turning a page and in a moment's time whether a motion is in order.

Between each marginal reference will be found in a condensed form all the rules relating to that particular question.

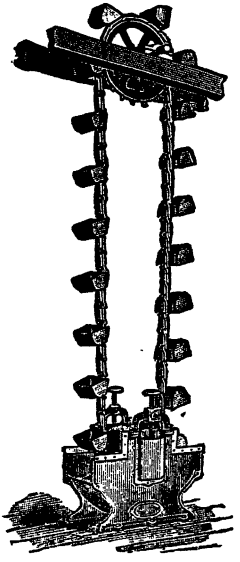
The book is so arranged that it can be carried in the pocket. Bound in cloth. It will be found to be of invaluable aid to those who are required to decide questions of Parliamentary Law without reference to larger text-books.

PRICE, 50 CENTS

THE SCIENTIFIC PUBLISHING CO., Publishers,

NEW YORK.

Elevating Machinery



OF EVERY DESCRIPTION,

—FOR—

ROCK AND PEBBLE PHOSPHATE.

WE FURNISH

Chain Belting, Elevators, Conveyors, Crushers, Washers, Screens, Dryers, Etc., Etc.

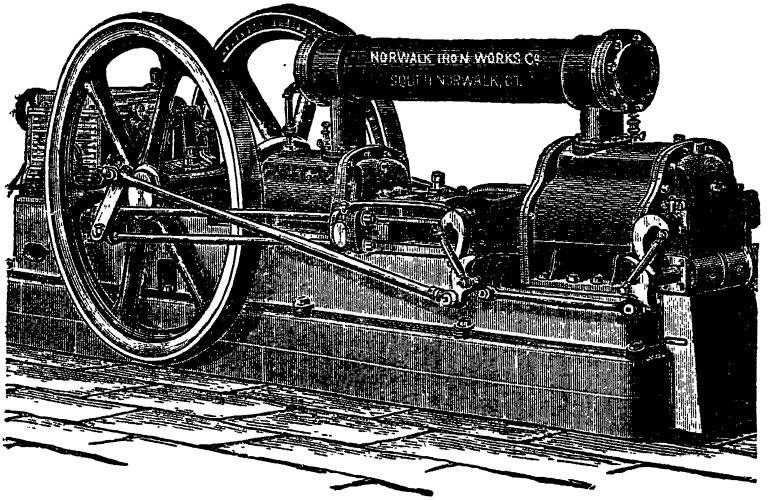
We have equipped some of the largest Phosphate plants in the country. Will furnish plans and estimates on complete outfit, or any parts that may be desired.

SEND FOR CATALOGUE.

THE JEFFREY MFG. CO.

COLUMBUS, O.

AIR COMPRESSORS.



THE NORWALK IRON WORKS CO.,

Circulars. SOUTH NORWALK, CONN.

Universal Bimetallism

AND

An International Monetary Clearing House,

TOGETHER WITH

A RECORD OF THE WORLD'S MONEY,
STATISTICS OF GOLD AND SILVER, ETC.

BY

RICHARD P. ROTHWELL, M.E., C.E.,

Editor of the "Engineering and Mining Journal,"
Ex-President American Institute of Mining Engineers,
Special Agent of the 11th United States Census on Gold and Silver, Etc., Etc.

PRICE, 75 CENTS.

This important contribution is a practical business man's solution of the great question which has brought upon the entire world the most acute financial crisis of modern times.

It proposes a simple, absolute, and permanent solution of this problem by the well-tried and universally successful agencies, International Arbitration and Clearing House Methods.

THE SCIENTIFIC PUBLISHING CO., Publishers,
NEW YORK.

IF YOU WISH

Any device for regulating steam, write to the MASON REGULATOR CO., of Boston, Mass. We also send, for 30 cents in stamps, our little book, "Key to Steam Engineering," serviceable to anyone in charge of a steam plant.

McLANAHAN & STONE, Gaysport Foundry, Hollidaysburg, Pa. **ENGINEERS & MANUFACTURERS,**

IMPROVED PHOSPHATE WASHERS.
Revolving Screens, Steel Pan Conveyors, Elevators, etc.
Complete Plants for Mining and Dressing Phosphate.

ESTABLISHED 1866. **INCORPORATED 1888.**

HENRY HEIL CHEMICAL CO.,

208-212 South Fourth St., St. Louis, Mo.,

MANUFACTURERS AND IMPORTERS OF

CHEMICALS AND CHEMICAL APPARATUS,

ASSAYERS' MATERIALS,

Crucibles, Scorifiers, Muffles, Furnaces and Supplies for Chemists, Mines, Smelters, Sampling Works and Stamp Mills.

AGENTS FOR

J. H. Munktell's Swedish Filtering Paper, The Denver Fire Clay Co.'s Crucibles, Muffles and other Manufactures.

Battersea Crucibles, Muffles, Etc.,

Josef Kavalier's Unexcelled Bohemian Glassware, Etc.

All and everything the Chemist and Assayer needs can be found at our establishment. We guarantee best quality and lowest prices. Write for our Catalogue, which is larger and more complete than any other, containing 3,000 illustrations.

THE UNANIMOUS OPINION

OF THE BEST CRITICAL JUDGMENT OF THE WORLD IS THAT THIS WORK IS THE

MASTERPIECE OF LITERARY, ARTISTIC AND TYPOGRAPHICAL ART.

GEMS

AND

PRECIOUS STONES

OF

NORTH AMERICA

A POPULAR DESCRIPTION

OF THEIR OCCURRENCE, VALUE, HISTORY, ARCHÆOLOGY, AND OF THE COLLECTIONS IN WHICH THEY EXIST, ALSO A CHAPTER ON PEARLS AND ON REMARKABLE FOREIGN GEMS OWNED IN THE UNITED STATES . . . .

ILLUSTRATED

WITH EIGHT COLORED PLATES AND NUMEROUS MINOR ENGRAVINGS

BY

GEORGE FREDERIC KUNZ,

Gem Expert with Messrs. Tiffany & Co., special agent of the United States Geological Survey and of the Eleventh United States Census, member of the Mineralogical Society of Great Britain and Ireland, the Imperial Mineralogical Society of St. Petersburg, the Société Française de Minéralogie, etc.

Price, - - $10.00

SCIENTIFIC PUBLISHING COMPANY,

27 PARK PLACE, NEW YORK.

THE

ORE DEPOSITS

OF THE

UNITED STATES.

BY

J. F. KEMP, A.B., E.M.,

PROFESSOR OF GEOLOGY IN THE SCHOOL OF MINES, COLUMBIA COLLEGE.

Bound in Cloth. Elaborately Illustrated. Price, $4.00.

TABLE OF CONTENTS.

PART I.—Introduction.

CHAPTER I.—General Geological Facts and Principles.
CHAPTER II.—On the Formation of Cavities in Rocks.
CHAPTER III.—The Minerals Important as Ores: The Gangue Minerals and the Sources whence both are derived.
CHAPTER IV.—On the Filling of Mineral Veins.
CHAPTER V.—On Certain Structural Features of Mineral Veins.
CHAPTER VI.—The Classification of Ore Deposits; a Review and a Scheme Based on Origin.

PART II.—The Ore Deposits.

CHAPTER I.—The Iron Series (in part). Introductory Remarks on Iron Ores. Limonite. Siderite.
CHAPTER II.—The Iron Series (continued). Hematite, Red and Specular.
CHAPTER III.—Magnetite and Pyrite.
CHAPTER IV.—Copper.
CHAPTER V.—Lead Alone.
CHAPTER VI.—Lead and Zink.
CHAPTER VII.—Zinc Alone, or with metals other than lead.
CHAPTER VIII.—Lead and Silver.
CHAPTER IX.—Silver and Gold. Introductory: Eastern Silver Mines and the Rocky Mountain Region of New Mexico and Colorado.
CHAPTER X.—Silver and Gold (continued). Rocky Mountain Region, Wyoming, the Black Hills, Montana and Idaho.
CHAPTER XI.—Silver and Gold (continued). The Region of the Great Basin, in Utah, Arizona and Nevada.
CHAPTER XII.—The Pacific Slope. Washington, Oregon and California.
CHAPTER XIII.—Gold elsewhere in the United States and Canada.
CHAPTER XIV.—The Lesser Metals. Aluminum, Antimony, Arsenic, Bismuth, Chromium, Manganese.
CHAPTER XV.—The Lesser Metals (continued). Mercury, Nickel, Cobalt, Platinum, Tin.

THE SCIENTIFIC PUBLISHING COMPANY,

PUBLISHERS,

THE MINERAL INDUSTRY,

Its Statistics, Technology, and Trade

IN THE

UNITED STATES AND OTHER COUNTRIES FROM THE EARLIEST TIMES.

Vol. I. STATISTICS TO THE END OF 1892, . . Price, $2.50.
Vol. II. STATISTICS TO THE END OF 1893, . . Price, $5.00.

BY

R. P. ROTHWELL, C.E., M.E.,

Editor of the "Engineering and Mining Journal."

These are the most thorough and exhaustive works on the mineral productions and industries of the world that have ever been issued, and no person at all interested in mining or metallurgy can afford to be without them.

THE SCIENTIFIC PUBLISHING COMPANY,

Publishers and Booksellers,

NEW YORK: 27 Park Place.

LONDON: 20 Bucklersbury.

THE ENGINEERING AND MINING JOURNAL

RICHARD P. ROTHWELL C.E., M.E., Editor.
ROSSITER W. RAYMOND, Ph.D., M.E., Special Contributor.
SOPHIA BRAEUNLICH, Business Manager.

ESTABLISHED 1866.

Its reports, criticisms on the technical information it gives, its market reports, and its peerless and impartial criticisms of things calculated to injure legitimate mining investments have gained the approval and confidence of the entire mining industry.

The Largest Circulation of any Technical Paper in America.

BEST ADVERTISING MEDIUM.

Circulating Among the Largest Buyers of Tools, Hardware, Machinery of all kinds, Railway and Mining Supplies in every part of the World.

PUBLISHED WEEKLY.—ILLUSTRATED.

SUBSCRIPTION PRICE: For United States, Mexico, and Canada, $5.00 per annum; $2.50 for six months; all other countries in the Postal Union, $7.00.

THE SCIENTIFIC PUBLISHING CO., Publishers,

NEW YORK.

MODERN AMERICAN METHODS OF COPPER SMELTING,

BY

EDWARD D. PETERS, Jr., M. E., M. D.

No one who has a copy of the First Edition of this great work should fail to secure the Second Edition, Revised and Enlarged.

Profusely Illustrated. Price $4.00.

This is the Best Book on Copper Smelting in the language.

It contains a record of practical experience, with directions how to build furnaces and how to overcome the various metallurgical difficulties met with in copper smelting.

TABLE OF CONTENTS.

Chapter I.—Description of the Ores of Copper.
Chapter II.—Distribution of the Ores of Copper.
Chapter III.—Methods of Copper Assaying.
Chapter IV.—The Roasting of Copper Ores in Lump Form.
Chapter V.—Stall Roasting.
Chapter VI.—The Roasting of Ores in Lump Form in Kilns.
Chapter VII.—Calcination of Ore and Matte in Finely Divided Condition.
Chapter VIII.—The Chemistry of the Calcining Process.
Chapter IX.—The Smelting of Copper.
Chapter X.—Blast Furnaces Constructed of Brick.
Chapter XI.—General Remarks on Blast Furnace Smelting.
Chapter XII.—Late Improvements in Blast Furnaces.
Chapter XIII.—The Smelting of Pyritous Ores Containing Copper and Nickel.
Chapter XIV.—Reverberatory Furnaces.
Chapter XV.—Refining Copper Gas in Sweden.
Chapter XVI.—Treatment of Gold and Silver Bearing Copper Ores.
Chapter XVII.—The Bessemerizing of Copper Mattes.
General Index, Etc.

THE SCIENTIFIC PUBLISHING COMPANY,

PUBLISHERS,

27 PARK PLACE, NEW YORK.

THE METALLURGY OF LEAD

AND THE

DESILVERIZATION OF BASE BULLION

BY

H. O. HOFMAN, E. M., Ph. D.,

Associate Professor of Mining and Metallurgy, Massachusetts Institute of Technology.

Bound in Cloth. Illustrated with Working Drawings.

PRICE, $6.00.

TABLE OF CONTENTS.

PART I. INTRODUCTION.

Chapter I Historical and Statistical Notices.
" II Properties of Lead and some of its Compounds.
" III Lead Ores.
" IV Distribution of Lead Ores.
" V Receiving, Sampling and Purchasing of Ores, Flues and Fuel.

PART II. METALLURGICAL TREATMENT OF LEAD ORES.

Chapter VI Smelting in the Reverberatory Furnace.
" VII " " Ore "
" VIII " " Blast "

PART III. DESILVERIZATION OF BASE BULLION.

Chapter IX Pattinson Process.
" X Parkes "
" XI Cupellation "

THE SCIENTIFIC PUBLISHING COMPANY,

PUBLISHERS,

27 PARK PLACE, NEW YORK.

THE

MINING LAWS

OF THE

REPUBLIC OF COLOMBIA

WITH

A SHORT EXPLANATION OF THEIR APPLICATION

AND

OFFICIAL FORMS FOR NOTICES, DENOUNCEMENTS

AND APPLICATIONS FOR TITLE.

TRANSLATED AND EDITED

BY

CHARLES BULLMAN, M.E.

BOUND IN CLOTH, 113 PAGES, • PRICE, $1.50.

THE SCIENTIFIC PUBLISHING COMPANY,
PUBLISHERS,
27 PARK PLACE, NEW YORK.

THE METALLURGY OF STEEL,

BY

HENRY M. HOWE, A.M., S.B.

Royal Quarto, Handsomely Bound, Printed on Superfine Paper, and Profusely Illustrated.

SECOND EDITION.

Price, - - - - - *$10.00.*

This work is the most notable contribution to the literature of iron and steel metallurgy ever published. The series of papers on the subject which have appeared as supplements to the "Engineering and Mining Journal" during the past two years have attracted world-wide attention and have received the heartiest commendation from all quarters. The volume now published presents this material in much more convenient shape, with considerable additional matter, giving the results of the most recent research, experiment and practice. Mr. Howe also presents a complete review of all important conclusions reached by earlier investigators, and his masterly discussion of them renders the work classic. Every statement and citation has been carefully weighed and verified and the references to the literature of the subject are given minutely, the book thus furnishing in itself a key to the whole range of steel metallurgy. It also furnishes the results of much new and original investigation, specially undertaken for the present work.

Every metallurgist, every manufacturer of steel in any form, and all who are interested in the iron or steel industries, and all engineers who use iron or steel should have this standard work and cannot afford to be without it.

The unprecedented demand exhausted the first edition in a few weeks. The second edition has been revised and enlarged.

SCIENTIFIC PUBLISHING COMPANY,

PUBLISHERS,

27 PARK PLACE, NEW YORK.

MANUAL

OF

QUALITATIVE BLOWPIPE ANALYSIS

AND

DETERMINATIVE MINERALOGY.

BY

F. M. ENDLICH, S. N. D.,

MINING ENGINEER AND METALLURGIST,

LATE MINERALOGIST SMITHSONIAN INSTITUTION, AND UNITED STATES GEOLOGICAL AND GEOGRAPHICAL SURVEY OF THE TERRITORIES.

Bound in Cloth. Illustrated. Price $4.00.

This work has been specially prepared for the use of all students in this great department of chemical science. The difficulties which beset beginners are borne in mind, and detailed information has been given concerning the various manipulations. All enumerations of species as far as possible have been carried out in alphabetical order, and in the determinative tables more attention has been paid to the physical characteristics of substances under examination than has ever yet been done in a work of this kind. To a compilation of all the blowpipe reactions heretofore recognized as correct the author has added a number of new ones not previously published. The entirearrangement of the volume is an original one, and to the knowledge born of an extensive practical experience the author has added everything of value that could be gleaned from other sources. The book cannot fail to find a place in the library or workshop of almost every student and scientist in America.

TABLE OF CONTENTS.

Chapter I.—Appliances and Reagents required for Qualitative Blowpipe Analysis.
Chapter II.—Methods of Qualitative Blowpipe Analysis.
Chapter III.—Tables giving Reactions for the Oxides of Earth and Minerals.
Chapter IV.—Prominent Blowpipe Reactions for the Elements and their Principal Mineral Compounds.
Chapter V.—Systematic Qualitative Determination of Compounds.
Chapter VI.—Determinative Tables and their Application.

THE SCIENTIFIC PUBLISHING COMPANY,

PUBLISHERS,

27 PARK PLACE, NEW YORK.

AN OUTLINE

OF

QUALITATIVE ANALYSIS

BY

JOHN A. MILLER, M.Sc., A.M., Ph.D., (Berlin),

Professor of Medical Chemistry and Toxicology, and Director of the Chemical Laboratory at the Medical Department of the Niagara University of Buffalo, N. Y.; Member of the Berlin Chemical Society; Fellow of the London Chemical Society; Member of the American Chemical Society and of the American Microscopical Society; Fellow of the Royal Microscopical Society.

A laboratory manual giving in a clear and concise manner all the reactions for the elements commonly met with, and the best methods for their separation and identification. The acids are also treated in the same manner. The table for the detection of the acids is simple, clear and concise, thus rendering the detection of the acids an easy task.

PRICE, BOUND IN CLOTH, $1.50.

THE SCIENTIFIC PUBLISHING CO., Publishers,

New York.

THE

CANADIAN ICE AGE.

BEING

NOTES ON THE PLEISTOCENE GEOLOGY OF CANADA, WITH ESPECIAL REFERENCE TO THE LIFE OF THE PERIOD AND ITS CLIMATAL CONDITIONS.

BY

Sir J. WILLIAM DAWSON, C.M.G.,
LL.D., F.R.S., F.G.S., Etc.

This book contains information bearing on the history of the northern half of the continent of North America in that Ice Age which was in some sense peculiarly its own.

The author has long been convinced that we must take into account the agency both of land ice and sea-borne ice in many forms, along with repeated and complex elevations and depressions of large portions of the continent, in order to account for the effects observed. He is disposed, however, to seek for the causes of changes of climate rather in geological and geographical agencies than in astronomical vicissitudes, some of which are too slow and uncertain in their operation, and others altogether conjectural. Such views are less sensational than those which invoke vast and portentous exaggerations of individual phenomena, but they are likely, in the end, to commend themselves to serious thinkers, especially when they are confirmed by the facts observed in the regions which are, of all others, best suited for the study both of extinct and recent ice-action.

TABLE OF CONTENTS.

Chapter I. Historical Details.
Chapter II. The Succession of Deposits.
Chapter III. Physical and Climatal Conditions.
Chapter IV. Physical and Climatal Conditions, Continued.
Chapter V. Some Local Details.
Chapter VI. Pleistocene Fossils.
Chapter VII. General Conclusions.

A Book that every Student of Geology should read.

CLOTH, PRICE, $2.00.

THE SCIENTIFIC PUBLISHING CO.,
Publishers and Booksellers,
NEW YORK AND LONDON.

Florida, South Carolina AND Canadian

PHOSPHATES.

Giving a Complete Account of Their Occurrence, Methods and Cost of Production, Quantities Raised, and Commercial Importance.

—BY—

C. C. HOYER MILLAR.

The author gives his experience and investigations during the last few years in the Phosphate Fields of Florida, South Carolina and Canada.

Bound in Cloth, 223 pages; Price, $2.50.

TABLE OF CONTENTS.

Chapter I. Introduction.
Chapter II. Florida Phosphates.
Chapter III. South Carolina Phosphates.
Chapter IV. Canadian Phosphates.

Appendix—Analysis of Various Phosphates.

THE SCIENTIFIC PUBLISHING COMPANY,
27 Park Place, New York.

UNIVERSAL LIBRARY
109 144
UNIVERSAL LIBRARY